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ERRATA

Page 32, Table XX, "*Trifolium repens*" should read "*Trifolium pratense.*"

Page 52, Table XXX, "*Linum usatissimum*" should read "*Linum usitatissimum.*"

Page 52, Table XXX, "*Cucumbis sativa*" should read "*Cucumis sativus.*"

Page 53, Table XXX, "*Boutelona gracilis*" should read "*Bouteloua gracilis.*"

Page 53, Table XXXI, "*Cucumis sativa*" should read "*Cucumis sativus.*"

Page 56, Table XXXIII, column head, "Ratio, 1913 to 1912," should read "Ratio, 1912 to 1913."

Page 56, line 4 from bottom, "75 ± 2" should read "75 ± 1."

Page 97, line 26, "*Salix nutallii*" should read "*Salix nuttallii.*"

Page 106, Table II, "*Sutanion velutinum*" should read "*Sitanion velutinum.*"

Page 165, Table III, insert line after "MgO" to read "Fe_2O_3....0.07 0.10 0.09 0.10."

Page 165, Table IV, "Fl_2O_3" should read "Fe_2O_3."

Page 165, Table IV, "Total...................... 99.94 ...... 98.36 ......"
should read "Total.............................. 99.94 99.54 100.36 100.00."

Page 166, Table V, "Total.................... 104.45 104.82 101.41 101.99"
should read "Total .... 99.73 100.04 99.25 99.81."

Page 256, line 10, "($C_1=t-t_m;\ C_2=C_1^2-(C_1^2);_m\ N=D_t-(D_t)_m.$)" should read "$C_1=t-t_m;\ C_2=C_1^2-(C_1^2)_m;\ N=D_t-(D_t)_m$."

Page 256, line 11, "($\Sigma C_1^2\alpha+\Sigma C_{12}\beta C=\Sigma C_1N.$)" should read "$\Sigma C_1^2\alpha+\Sigma C_1C_2\beta=\Sigma C_1N$."

Page 278, lines 37–38, "(fig. 2)" should read "(fig. 3)."

Page 279, line 19, "as" should read "at."

Page 279, legend for figure 2, "Side views of basal portions, etc.," should read "Fig. 2.—Detail drawings of ventral view of seeds of *Agropyron* spp.: *A*, *Agropyron repens; B*, *A. smithii; C*, *A. tenerum*. $\times$ 9."

Page 280, legend for figure 3, "Detail drawings of ventral view, etc.," should read "Fig. 3.—Side views of basal portions of seeds of *Agropyron* spp., showing the relative projection of the rachilla: *A*, *Agropyron repens; B*, *A. smithii; C*, *A. tenerum*. $\times$ 9."

Page 280, legend for figure 4, "Edge of rachilla in *Agropyron* spp., etc.," should read "Fig. 4.—Edge of palea in *Agropyron* spp., showing space and comparative size of bristles: *A*, *Agropyron repens; B*, *A. smithii; C*, *A. tenerum*. $\times$ 9."

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RELATIVE WATER REQUIREMENT OF PLANTS

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INTRODUCTION

The marked differences in the quantity of water required by different species of plants for the production of a given weight of dry matter when grown under the same environmental conditions is a matter of scientific interest and of great economic importance in regions of limited water supply. The measurements which have heretofore been made have for the most part been limited to a few species and have been carried out under such varied environmental conditions that comparison is difficult. The writers have therefore undertaken the measurement of the water requirement of representative species and varieties of the principal crop plants, grown at the same place and under as nearly uniform conditions as to time as the temperature requirement and life history of the different crops will permit. The first series of measurements were made at Akron, Colo., in 1911 (Briggs and Shantz, 1913a)[1]. These measurements were extended in 1912 and 1913 to include many species whose water requirement had never before been determined. The later measurements form the subject of the present paper. The writers desire to express their obligation to Messrs. R. D. Rands, A. McG. Peter, H. Martin, F. A. Cajori, N. Peter, and G. Crawford for efficient and painstaking assistance in connection with these experiments.

EXPERIMENTAL CONDITIONS

The experimental procedure in 1912 and 1913 was similar to that in the earlier experiments. The plants were grown to maturity in large galvanized-iron pots holding about 115 kg. of soil. Each pot was provided with a tight-fitting cover having openings for the stems of the plants, the annular space between the stem of the plant and the cover being sealed with wax. The loss of water was thus confined almost entirely to that taking place through the leaves, and the entrance of rainfall was almost wholly excluded. The wax which has been found to be the most

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 62–63.

satisfactory for sealing the openings about the stems consists of a mixture of four parts of unrefined beeswax with one part of tallow.

Six pots of plants of each variety [1] were used, and the water requirement of each pot was determined independently, in order to provide a basis for the calculation of the probable error of the mean. In making this calculation, Peter's abridged method, based upon the sum of the departures, has been employed.[2]

The term "water requirement," when employed in the following pages without further restriction, indicates the ratio of the weight of water absorbed by a plant during its growth to the weight of the dry matter produced, exclusive of the roots (Briggs and Shantz, 1913a, p. 7). The plants were dried to constant weight in a steam-heated oven, maintained at approximately 110° C. When the plants produced grain, the water requirement based upon the weight of the dry grain is also given. The percentage of grain produced by the plants grown in the pots usually compared favorably with the field performance. Unless a normal percentage of grain is produced, the water-requirement ratio based on grain production should not be applied to crops grown under field conditions. In a few instances the water requirement based upon the weight of roots or tubers has also been determined.

SCREENED INCLOSURE

To protect the plants from birds and severe hail and wind storms, it was found necessary to conduct the experiments in a screened inclosure. The inclosure used in 1911 consisted of a wooden framework covered with wire netting of ¼-inch mesh. This framework shaded the plants somewhat, being made sufficiently rigid to support a track above each row of cans, from which the cans were suspended during weighing. To reduce the shading effect, a new inclosure was provided in 1912, the framework of which was made of 1-inch galvanized-iron pipe with pipe posts 9 feet high at intervals of 8 feet. The framework to a height of 3 feet was covered with a wooden wall which came slightly above the top of the pots. The remainder was covered with No. 21 galvanized-wire netting of ⅜-inch mesh. General views of the inclosure are shown in Plate I.

Although the new inclosure reduced the shading effect, pyrheliometric and total radiation measurements made inside and outside the inclosure still showed a measureable reduction in the radiation due to the shade of the screen. Measurements made with an Abbot silver-disk pyrheliometer (Abbot, 1911) showed that the intensity of the direct radiation

[1] The recorded strains used in these measurements were obtained from the following offices of the Bureau of Plant Industry: Foreign Seed and Plant Introduction (S. P. I.); Cereal Investigations (C. I.); Alkali and Drought Resistant Plant Investigations (A. D. I.).

[2] The formula used was $R_m = 0.845 \frac{\Sigma d}{n\sqrt{n-1}}$, where R_m = the probable error of the mean, Σd = the sum of the departures, and n = number of determinations.

A probable error based upon six determinations does not necessarily represent strictly the actual frequency diagram, and this must be borne in mind in the consideration of probable errors. For a discussion ... is small, see "Student" (1908).

from the sun was reduced about 20 per cent by the inclosure at midday in midsummer, while total radiation measurements made with a differential telethermograph (Briggs, 1913) gave approximately the same reduction. Simultaneous measurements of the water requirement of wheat, alfalfa, and cocklebur grown inside and outside the inclosure in 1913 showed that the inclosure reduced the water requirement about 22 per cent. The water-requirement measurements must therefore be considered relative rather than absolute. In this connection it should be recalled that plants growing under field conditions are also mutually shaded and otherwise protected to some extent. The writers' measurements in 1913 show that wheat grown in pots sunk in trenches and surrounded by a field of grain has a water requirement 10 per cent above wheat grown in the inclosure and 10 per cent below wheat grown outside the inclosure in a freely exposed wind-swept position. (See Table I.) The stand of wheat about the trench was below normal, owing to the disturbance of the plants in trenching and in caring for the pots. The potted plants in the trenches were consequently more exposed than if growing normally in a field of grain. The water requirement of the potted plants in the trench is therefore somewhat above that of plants normally protected. From this comparison it appears that the inclosure measurements, at least in the case of wheat, are less than 10 per cent below the water requirement of plants exposed under field conditions.

TABLE I.—*Effect of the screened inclosure on the water requirement of wheat at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka, C. I. 1440 (*Triticum durum*), check series, May 22 to Aug. 13.	7	162.2	56.5	103.8	35	1,837	640
	8	167.4	63.9	105.1	38	1,645	628
	9	143.4	49.0	91.2	35	1,861	636
	10	151.6	51.4	93.1	34	1,810	614
	11	148.9	56.5	89.5	38	1,584	601
	12	159.3	50.3	102.2	32	2,032	642
Mean						1,795±43	627±5
Kubanka, in field, May 22 to Aug. 13.	1	142.5	46.6	81.4	33	1,745	571
	2	151.1	43.9	80.8	29	1,840	534
	3	153.4	48.9	82.9	32	1,694	540
	4	156.0	42.8	88.4	27	2,063	566
	5	143.9	48.2	83.3	33	1,726	579
	6	167.8	44.9	97.3	27	2,167	580
Mean						1,873±61	562±6
Kubanka, in shelter, May 23 to Aug. 13.	73	294.8	106.5	150.3	36	1,410	510
	74	273.4	101.4	135.9	37	1,340	497
	75	257.0	97.1	122.4	38	1,261	476
	76	304.2	116.2	156.0	32	1,342	513
	77	253.3	93.8	121.3	37	1,293	479
	78	299.6	116.8	150.2	39	1,286	502
Mean						1,322±16	496±5

WEIGHING AND WATERING

The discarding of the overhead track necessitated the construction of a movable support for weighing the cans. The weighing support used is shown in Plate II, figure 2. It was constructed of 1-inch galvanized-iron pipe and consisted of a crossbar which spanned the row and which was supported at each end by two bent posts. These posts were fitted with floor plates secured to two wooden skids, which slid along the ground on either side of the row of cans. In the earlier weighings the pots were suspended from a rope running through pulleys to a small windlass located on one of the posts of the support (Pl. II, fig. 2). The windlass was later located directly beneath the crossbar and was operated through a chain-and-sprocket drive.

Each pot was provided with bale ears by which it could be suspended directly from the balance by chains. When the plants were not sufficiently high to come in contact with the weighing apparatus, pots could be weighed at the rate of two a minute if two men handled the support and a third recorded the weight. When 300 pots or more are to be weighed three times a week, as was the case at Akron, rapidity in weighing becomes important.

The initial and final weighings have been made with an accuracy of one-fifth of a kilogram, either with a platform balance or a sensitive spring balance calibrated and corrected for temperature. Intermediate weighings have been made throughout with a spring balance calibrated by means of a sealed check pot weighing 130 kg.

The water in all cases has been added from calibrated 2-liter flasks (Briggs and Shantz, 1913a, p. 11). The neck of each flask is cut so as to deliver 2 liters of water when brimful. The flasks are filled by submersion. In some of the later work a tank with a framework arranged for keeping a number of flasks submerged has been used. No time is thus lost in filling flasks or in adjusting the contents to a fiducial mark.

SOIL FERTILIZER

Surface soil from the experiment farm was used for filling the pots. Since it is well known that the water requirement is increased by a deficiency in the plant food supply (Briggs and Shantz, 1913b, pp. 31–56), the same quantity of a complete soluble fertilizer was added to each pot at each station at intervals during the growth of the crop. The fertilizer in 1912 was applied at the rate of 50 p. p. m. of PO_4, 100 p. p. m. of NO_3, and 65 p. p. m. of K, all based on an assumed dry soil mass of 100 kg. per pot.[1] The phosphoric acid was applied as sodium phosphate; the nitrogen and potash as potassium nitrate. This amount of fertilizer was divided into four equal portions and applied at intervals during the active growth of the crops, the first application being made soon after

[1] Approximately one-half of this quantity was used in 1913 and was applied as in 1912.

the plants had become well established. In practice it was found convenient to make up a large quantity of the fertilizer solution of such concentration that 2 liters contained one-fourth of the total quantity required for one pot. The addition of this quantity to each pot was followed immediately by 2 liters of water.

To test the influence of the fertilizer, one standard set of six pots of Kubanka wheat was grown without fertilizer at Akron, for comparison with the fertilized sets. The detailed results are given in Table II. The water requirement of the unfertilized set was 4 ± 2 per cent below that of the fertilized set when based on the production of dry matter, and 1 ± 4 per cent above, when based on grain production. The results therefore indicate that the additional plant food was not needed at this station, the water requirement of the two sets agreeing (within the errors of the experiment) whether based on the production of dry matter or on the production of grain. In 1911 the water requirement of the unfertilized set[1] at Akron was 6 ± 3 per cent above the fertilized set when compared on the basis of dry matter, although the ratios based on grain production were the same.

TABLE II.—*Effect of fertilizer on the water requirement of wheat at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka, C. I. 1440 (*Triticum durum*), May 9 to Sept. 3, fertilized	1	270.0	108.2	95.1	40	879	352
	2	252.7	88.3	97.1	35	1,099	384
	3	279.4	98.1	109.9	32	1,120	393
	4	288.8	99.7	118.6	35	1,190	411
	5	291.8	99.5	122.0	34	1,226	418
	6	261.7	92.2	106.2	35	1,152	406
Mean						$1,111\pm37$	394 ± 7
Kubanka, C. I. 1440, May 9 to Aug. 21, unfertilized	7	291.8	102.8	108.6	35	1,056	372
	8	272.3	100.6	107.4	37	1,067	394
	9	290.3	101.1	108.8	35	1,076	375
	10	274.8	79.5	109.4	29	1,375	398
	11	300.2	105.7	114.1	35	1,080	380
	12	263.2	87.6	88.4	33	1,090	336
Mean						$1,124\pm32$	376 ± 6

CLIMATIC FACTORS

The instrumental equipment for the measurement of climatic factors included maximum and minimum thermometers and an air thermograph exposed in a standard shelter 4 feet above the ground surface, an anemometer, a psychrometer, a rain gauge, and an evaporation tank.

[1] Based on pots 1 to 6, unfertilized, which had the same exposure as pots 7 to 12, fertilized.

The sunshine, the wind velocity, the combined sun and sky radiation, the wet bulb depression, and the evaporation were automatically recorded. The results of some of these measurements, combined in 5-day periods for the sake of brevity, though not without sacrifice, are given in Tables III and IV. The discussion of the influence of climate on water requirement has purposely been restricted, since such correlations as may exist can best be determined when discussed in connection with the results from other stations established for this purpose.

TABLE III.—*Summary of climatic conditions at Akron, Colo., in 1912*

Month.	Days (inclusive).	Air temperature (°F.). Average of— Means.	Air temperature (°F.). Average of— Maximums.	Air temperature (°F.). Average of— Minimums.	Air temperature (°F.). Maximum.	Air temperature (°F.). Minimum.	Precipitation.	Evaporation.	Wind velocity per hour.
1912.							*Inches.*	*Inches.*	*Miles.*
April	1 to 5	48	62	33	73	29	.....	0.82	7.7
	6 to 10	44	60	29	69	23	0.26	.71	8.5
	11 to 15	44	56	30	68	26	.51	.71	14.7
	16 to 20	40	49	29	54	26	.36	.47	9.5
	21 to 25	46	57	32	70	27	.03	.78	9.6
	26 to 30	49	62	35	69	32	1.33	1.09	9.5
May	1 to 5	50	67	35	76	28	.35	.98	10.4
	6 to 10	53	66	41	75	34	.40	.90	8.3
	11 to 15	44	53	36	65	32	.97	.60	8.6
	16 to 20	61	77	47	83	41	Tr.	.99	6.9
	21 to 25	64	78	47	84	42	Tr.	1.32	7.1
	26 to 31	60	77	44	92	35	1.14	2.31	9.3
June	1 to 5	64	78	49	83	45	.....	1.32	7.8
	6 to 10	59	69	49	78	47	.41	.74	8.1
	11 to 15	60	72	49	84	44	1.03	.84	4.5
	16 to 20	55	65	41	78	37	1.51	1.00	4.3
	21 to 25	66	80	50	86	43	.....	1.21	5.5
	26 to 30	72	88	55	89	50	.44	1.64	6.1
July	1 to 5	66	81	49	87	46	.03	1.12	5.1
	6 to 10	73	89	55	96	51	.34	1.58	6.1
	11 to 15	70	86	54	92	51	.01	1.36	5.6
	16 to 20	69	82	55	90	50	.72	1.06	6.1
	21 to 25	73	88	59	94	55	1.63	1.38	5.5
	26 to 31	69	80	57	85	53	.85	1.12	4.1
August	1 to 5	68	79	58	84	54	.16	1.04	7.1
	6 to 10	65	79	50	85	48	.32	1.05	3.8
	11 to 15	69	83	54	89	50	.38	1.15	5.2
	16 to 20	68	82	53	86	51	.56	1.04	3.0
	21 to 25	72	89	56	95	52	.....	1.29	4.0
	26 to 31	72	88	56	96	53	.16	1.48	5.1
September	1 to 5	70	87	54	90	47	.....	1.39	6.4
	6 to 10	65	80	51	91	47	.43	1.08	7.1
	11 to 15	51	61	38	77	32	1.26	.61	5.6
	16 to 20	51	66	37	81	31	.....	.62	6.3
	21 to 25	46	59	34	71	22	.02	.54	6.3
	26 to 30	43	56	32	70	26	.17	.41	4.5

TABLE IV.—*Summary of climatic conditions at Akron, Colo., in 1913*

Month.	Days (inclusive).	Air temperature (°F.). Average of— Means.	Maxi-mums.	Mini-mums.	Maxi-mum.	Mini-mum.	Precipi-tation.	Evapo-ration.	Wind veloc-ity per hour.
1913.							*Inches.*	*Inches.*	*Miles.*
April	1 to 5	49	66	31	77	21	0.02	0.82	7.4
	6 to 10	33	46	24	73	10	.94	.78	12.4
	11 to 15	45	64	29	77	18	......	.31	3.6
	16 to 20	53	69	40	74	34	.87	.76	7.2
	21 to 25	44	55	34	68	27	.36	.51	11.0
	26 to 30	60	78	40	84	37	......	1.15	7.1
May	1 to 5	47	58	35	69	31	Tr.	.72	6.7
	6 to 10	54	68	43	81	41	.82	.84	8.9
	11 to 15	55	69	43	80	33	.54	.86	7.4
	16 to 20	55	70	42	80	38	Tr.	.93	7.6
	21 to 25	62	77	46	84	39	.02	.99	5.7
	26 to 31	69	86	51	91	48	.06	1.50	5.6
June	1 to 5	65	81	51	87	48	.26	1.15	6.2
	6 to 10	57	67	45	77	37	Tr.	1.07	10.3
	11 to 15	66	81	51	91	42	.16	1.17	9.0
	16 to 20	71	88	54	93	52	Tr.	1.27	6.6
	21 to 25	69	86	54	89	52	.51	1.33	5.8
	26 to 30	74	91	60	97	49	.42	2.19	10.3
July	1 to 5	75	92	56	100	53	......	1.71	7.0
	6 to 10	79	96	60	101	56	......	1.88	6.6
	11 to 15	74	92	56	103	46	.02	1.78	6.8
	16 to 20	68	83	56	93	53	1.12	1.27	4.8
	21 to 25	66	78	56	87	53	.61	1.01	6.8
	26 to 31	67	87	49	93	43	.10	1.61	5.0
August	1 to 5	78	95	61	98	57	......	1.75	5.8
	6 to 10	74	90	59	97	54	.05	1.54	6.2
	11 to 15	73	90	59	93	56	.81	1.23	4.9
	16 to 20	76	93	61	95	56	.24	1.38	5.0
	21 to 25	73	90	57	97	53	......	1.58	5.9
	26 to 31	75	91	59	98	54	.04	1.83	5.9
September	1 to 5	73	90	56	92	54	.17	1.37	4.8
	6 to 10	68	85	53	92	48	.45	1.27	6.7
	11 to 15	62	79	45	86	40	.10	1.30	7.6
	16 to 20	53	68	39	87	29	Tr.	.98	9.2
	21 to 25	45	59	32	76	27	.39	.61	5.6
	26 to 30	50	60	41	70	37	.97	.51	4.7

The months of June, July, August, and September, 1913, were all warmer than in 1912, the average difference in the monthly means being 4° F. In only 2 of the 24 five-day periods into which these months are divided did the mean maximum temperature in 1912 exceed that of 1913. The character of the two seasons is best reflected, however, in the evaporation graphs shown in figure 1. The evaporation for the two years was not essentially different up to the 1st of June. From this time on the evaporation in 1912 averaged much lower than in 1913.

The marked response of the plants to the different seasons is shown in the reduced water requirement in 1912. (See Tables XXXII, pp. 36–38, and XXXIII, p. 39.)

WATER REQUIREMENT OF VARIOUS CROPS

WHEAT

The water requirement of six varieties of wheat, including emmer, was measured at Akron in 1912. The results arranged in order of increasing water requirement based on dry matter are as follows:

Variety of wheat	Water requirement
Turkey	364±6
Kharkov	365±6
Kubanka	394±7
Emmer	428±3
Bluestem	451±4
Spring Ghirka	457±3

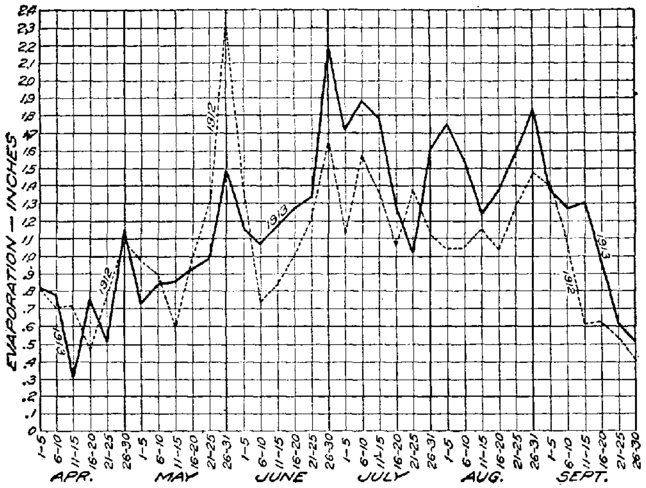

Fig. 1.—Evaporation from a free-water surface (tank) at Akron, Colo., in 1911 and 1912. Note the marked reduction in evaporation in 1912 after June 10. A volcanic eruption in Alaska occurred on June 6.

The Turkey and Kharkov varieties (Pl. III, fig. 6) were tested for the first time in 1912. These are winter varieties and were transplanted to the pots in the spring from field plats sown in the fall. They gave the same water requirement and appear to be about 10 per cent more efficient than the Kubanka (Pl. III, fig. 1), which has heretofore been the most efficient wheat tested as regards economy in the use of water. This comparison, however, ignores the small quantity of dry matter in

the plants at the time of transplanting. The three remaining varieties show somewhat greater differences than in 1911, and the order is reversed. The probable error of the water requirement of emmer in the 1911 experiments was abnormally high, so that the 1912 series (Pl. III, fig. 4, and Pl. VII, fig. 4) may be considered more nearly representative of the relative position of this crop.

The water requirement of different varieties based on grain production is as follows:

Variety of wheat	Water requirement
Emmer (including glumes)	984±18
Turkey	995±22
Kharkov	1,064±60
Kubanka	1,111±37
Emmer (without glumes)	1,243±23
Spring Ghirka	1,468±34
Bluestem	1,573±49

In order to reduce the results obtained with emmer to a basis comparable with the other varieties, the calculations should be made upon the weight of the grain without the glumes, which constitute about 21 per cent of the total weight. When this is done, it will be seen that the water requirement of the different varieties based on grain production follows the same order as when based on the production of dry matter. The Turkey wheat again gives the lowest value for the water requirement, although the Turkey, Kharkov, and Kubanka may be considered substantially in agreement when the errors of the experiment are considered. The detailed results are given in Table V.

TABLE V.—*Water requirement of different varieties of wheat at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka, C. I. 1440 (*Triticum durum*), May 9 to Sept. 3	1	270.0	108.2	95.1	40	879	352
	2	252.7	88.3	97.1	35	1,099	384
	3	279.4	98.1	109.9	32	1,120	393
	4	288.8	99.7	118.6	35	1,190	411
	5	291.8	99.5	122.0	34	1,226	418
	6	261.7	92.2	106.2	35	1,152	406
Mean						1,111±37	394±7
Marvel Bluestem, C. I. 3082 (*Triticum aestivum*), May 11 to Aug. 28	31	286.2	74.2	126.3	26	1,701	441
	32	333.0	93.1	147.4	28	1,582	443
	33	310.8	87.9	145.7	28	1,658	469
	34	298.8	77.2	134.3	26	1,740	450
	35	321.4	102.9	149.5	32	1,452	465
	36	334.3	111.8	145.7	33	1,303	436
Mean						1,573±49	451±4

TABLE V.—*Water requirement of different varieties of wheat at Akron, Colo., in 1912 and 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Kharkov, C. I. 1583 (*Triticum aestivum*), Apr. 27 to Aug. 28	37	365.6	91.6	138.0	25	1,505	377
	38	347.3	131.3	122.0	38	930	351
	39	360.0	128.7	141.6	36	1,100	394
	40	384.9	138.1	135.6	40	982	353
	41	326.9	124.4	121 5	38	978	372
	42	310.7	119.2	106 1	38	890	342
Mean						1,064±60	365±6
Turkey, C. I. 1571 (*Triticum aestivum*), Apr. 27 to Aug. 1	43	344.4	121.2	132 5	35	1,092	385
	44	328.4	112.4	120.0	34	1,070	365
	45	242.7	86.1	85.6	35	995	353
	46	308.0	119.6	106.7	39	892	346
	47	245.9	97.7	95.2	40	974	387
	48	274.4	100.8	95.4	37	946	348
Mean						995±22	364±6
Spring Ghirka, C. I. 1517 (*Triticum aestivum*), May 11 to Aug. 12	55	266.8	74.4	122.5	28	1,645	459
	56	263.3	81.0	120.6	31	1,489	458
	57	264.6	82.1	126.3	31	1,540	477
	58	275.9	90.2	125.6	33	1,393	456
	59	297.9	94.2	131.5	32	1,395	442
	60	314.7	105.2	141.6	33	1,347	450
Mean						1,468±34	457±3
Emmer, C. I. 2951 (*Triticum dicoccum*), May 11 to Aug. 12	61	351.5	155.6	145.1	44	932	413
	62	314.7	142.3	132.5	45	930	421
	63	352.8	146.1	158.0	41	1,080	448
	64	340.5	143.8	147.8	42	1,028	434
	65	358.1	159.7	151.6	42	950	423
	66	343.0	149.0	146.3	43	982	426
Mean						984±18	428±3
1913.							
Kubanka, C. I. 1440 (*Triticum durum*), May 23 to Aug. 13	73	294.8	106.5	150.3	36	1,411	510
	74	273.4	101.4	135.9	37	1,340	497
	75	257.0	97.1	122.4	38	1,261	476
	76	304.2	116.2	156.0	38	1,342	513
	77	253.3	93.8	121.3	37	1,293	479
	78	299.6	116.8	150.2	39	1,286	502
Mean						1,322±16	496±5

Only one variety of wheat, the Kubanka, was included in the measurements of 1913. This variety gave a water requirement 26 per cent above the 1912 ratio and 19 per cent above the 1911 ratio. The water requirement on the basis of grain production was 19 per cent higher than in 1912 and 11 per cent higher than in 1911.

OATS

The four varieties of oats employed in the water-requirement tests in 1912 were the same as those used in the 1911 experiments. The water requirement in 1912, based on the total dry matter produced, was as follows:

Variety of oats	Water requirement
Canadian	399±6
Swedish Select	423±5
Burt	449±3
Sixty-Day	491±13

The Canadian again proved to be the most efficient of the varieties tested. The differences exhibited by the first three varieties in the list are practically the same as in 1911.

Much trouble was experienced in obtaining a stand of Sixty-Day oats. The germination was very poor and a second and even a third planting failed to give a good stand, as is shown by the variations in the yield of the different pots. (Table VI.) This is, perhaps, the cause of the higher water requirement obtained for Sixty-Day oats, which in 1911 ranked next to the Canadian in efficiency.

The water requirement of the different oat varieties, based on grain production in 1912, was as follows:

Variety of oats	Water requirement
Swedish Select	1,103±18
Sixty-Day	1,172±133
Burt	1,224±55
Canadian	1,416±119

The probable error is high in all the determinations, except in the case of the Swedish Select (Pl. III, fig. 5), and the relative order of the varieties is consequently of little significance. It is, however, of interest to observe that the Canadian variety is the least efficient in the use of water from the standpoint of grain production, which is in accord with the 1911 experiments.

Swedish Select and Burt oats were also included in the 1913 measurements at Akron. On the basis of dry matter produced, the two varieties were equally efficient in the use of water. In the measurements of 1912 and 1911 these two varieties gave only slight differences, the 1911 and the 1912 results being in accord when the probable errors are considered. On the basis of grain production, the Burt was the more efficient in 1913, and the Swedish Select in 1912 and in 1911. No real differences of importance are shown in these two varieties when the measurements of the three years are considered.

TABLE VI.—*Water requirement of different varieties of oats at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
1912.							
Sixty-Day, C. I. 165 (*Avena sativa*), May 15 to Aug. 23	67	206.5	72.8	119.9	36	1,645	580
	68	287.7	147.9	131.8	51	892	458
	69	270.9	107.3	133.6	40	1,245	493
	70	93.9	......	41.6	......	......	444
	71	274.7	143.4	129.5	52	904	472
	72	248.9	......	124.7	......	......	501
Mean						1,172±133	491±13
Canadian, C. I. 444 (*Avena sativa*), May 17 to Sept. 16	73	227.1	80.9	91.1	36	1,125	401
	74	302.1	118.7	126.7	39	1,068	419
	75	233.5	50.4	89.1	22	1,767	382
	76	276.0	79.8	107.8	29	1,350	390
	77	158.3	......	59.3	......	......	375
	78	250.0	60.5	107.0	24	1,769	428
Mean						1,416±119	399±6
Burt, C. I. 293 (*Avena sativa*), May 15 to Aug. 23	79	352.8	138.8	153.5	39	1,106	435
	80	339.9	110.5	158.4	33	1,433	466
	81	299.5	93.8	135.8	31	1,448	453
	82	344.5	132.9	150.9	39	1,135	438
	83	351.5	147.8	160.3	42	1,085	456
	84	363.8	143.3	162.7	39	1,135	447
Mean						1,224±55	449±3
Swedish Select, C. I. 134 (*Avena sativa*), May 17 to Aug. 23	85	402.2	167.7	167.2	42	997	416
	86	395.7	145.9	171.5	37	1,176	434
	87	409.5	155.9	171.2	38	1,098	418
	88	412.2	152.9	164.0	37	1,073	398
	89	389.8	145.9	160.7	37	1,163	435
	90	366.8	144.5	161.0	39	1,113	439
Mean						1,103±18	423±5
1913.							
Swedish Select, C. I. 134 (*Avena sativa*), May 23 to Aug. 1	79	265.5	84.2	171.4	32	2,035	646
	80	250.1	83.0	164.2	33	1,979	656
	81	262.4	77.4	158.5	29	2,049	604
	82	296.7	106.9	175.3	36	1,640	591
	83	286.1	101.4	174.3	35	1,719	609
	84	291.9	95.0	174.0	33	1,831	596
Mean						1,876±55	617±9
Burt, C. I. 293 (*Avena sativa*), May 23 to July 25	85	243.7	93.4	148.8	38	1,594	611
	86	245.6	101.8	151.1	41	1,484	616
	87	240.4	87.6	156.5	36	1,787	650
	88	255.5	89.3	157.0	35	1,758	614
	89	250.0	94.7	155.7	38	1,644	623
	90	254.9	94.5	149.3	37	1,580	586
Mean						1,641±33	617±5

BARLEY

Barley is the most uniform in water requirement of the small-grain crops which the writers have tested. The four varieties grown at Akron in 1912 showed only slight differences in their water requirement. The results obtained, based upon the production of dry matter, were as follows:

Variety of barley	Water requirement
Beardless	403±8
Beldi	416±4
White Hull-less	439±1
Hannchen	443±3

These same varieties were also tested at Akron in 1911 and were found to be in practical agreement as regards their relative water requirement. The mean value of the water requirement was 27 per cent higher in 1911 than in 1912.

The results obtained with barley when the water requirement is based on grain production are less uniform than when the total dry matter is employed. Reference to Table VII will show that this is often due to a single pot which for some reason fails to set grain as abundantly as the rest of the series. The Beldi, a dwarf variety, showed the highest efficiency in the use of water in grain production. The White Hull-less (Pl. III, fig. 2) has a water requirement slightly above the other varieties, even when a correction is made for the naked character of the grain.

TABLE VII.—*Water requirement of different varieties of barley at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Hannchen, C. I. 531 (*Hordeum distichon*), May 16 to Aug. 28	91	301.5	141.7	138.1	47	974	458
	92	282.9	116.6	127.7	41	1,095	452
	93	281.1	103.5	124.2	37	1,200	442
	94	300.3	137.1	133.3	46	972	444
	95	309.2	145.5	134.9	47	926	436
	96	308.5	152.0	130.9	49	860	424
Mean						1,005±36	443±3
Beldi, C. I. 190 (*Hordeum vulgare*), May 16 to Aug. 12	97	230.5	101.5	93.9	44	925	407
	98	240.1	107.0	98.5	45	920	410
	99	243.0	109.2	99.5	45	910	409
	100	189.4	81.3	82.1	43	1,010	434
	101	223.8	101.6	97.0	45	954	434
	102	236.5	103.1	95.5	44	926	404
Mean						941±10	416±4
White Hull-less, C. I. 595 (*Hordeum vulgare*), May 16 to Aug. 12	103	271.2	95.3	119.7	35	1,256	441
	104	276.0	97.1	121.4	35	1,250	440
	105	273.1	95.6	119.4	35	1,249	437
	106	268.8	92.9	119.7	35	1,289	445
	107	273.8	99.5	118.4	36	1,190	433
	108	299.7	110.0	131.6	37	1,197	439
Mean						1,239±11	439±1

TABLE VII.—*Water requirement of different varieties of barley at Akron, Colo., in 1912*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Beardless, C. I. 716 (*Hordeum vulgare*), May 16 to Aug. 23	109	112.0	20.7	49.2	18	......	439
	110	144.1	21.9	56.1	15	......	389
	111	276.3	135.7	111.6	49	823	408
	112	227.5	92.2	93.8	40	1,017	412
	113	210.5	63.9	87.2	30	1,364	414
	114	291.3	120.2	103.7	41	862	356
Mean						1,017±83	403±8

RYE

The measurement of the water requirement of spring rye at Akron in 1911 showed a surprisingly high figure—54 per cent above that of Kubanka wheat. The 1912 measurements (Table VIII) gave 496±9 for the water requirement of rye when based on dry matter and 1,802±62 when based on grain production. The 1912 (dry matter) ratio is thus about 26 per cent above Kubanka wheat, a marked increase in the relative efficiency in comparison with the 1911 ratio. In fact, rye exhibited the greatest reduction in water requirement of all the crops tested in 1912.

A consideration of the water requirement of crops grown out of season in 1911 showed that rye was unusually efficient during the cool fall period. This result as well as the increase in efficiency in 1912 suggests that rye may be unusually responsive to climatic conditions and that it is relatively better adapted to low temperature than the other small grains.

TABLE VIII.—*Water requirement of rye at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Rye, spring, C. I. 73 (*Secale cereale*), May 16 to Aug. 23	115	210.6	57.8	96.2	27	1,664	457
	116	216.4	65.1	118.8	30	1,825	549
	117	179.2	52.6	84.3	29	1,603	470
	118	248.6	65.8	123.3	26	1,874	496
	119	234.5	54.7	120.1	23	2,195	512
	120	254.1	75.6	124.6	30	1,649	490
Mean						1,802±62	496±9

RICE

Rice was grown for the first time at Akron in 1912. The crop was slow in becoming established, and the growth period was relatively long. No grain was produced. The water requirement based on dry matter was 519±13 (Table IX). It thus appears that rice, although a crop normally grown with an abundant water supply and in a relatively humid climate, is about as efficient in the use of water as rye. Its relative position might be materially changed if the tests were made in a warmer climate.

Rice was also included in the 1913 measurements (Pl. VII, fig. 3). The stand was good and the growth was uniform and luxurious, but the season was too short to produce grain. The water requirement in 1913 was 744±17, or 43 per cent higher than in 1912.

TABLE IX.—*Water requirement of rice at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1912.		*Grams.*	*Kilos.*	
Rice, Honduras, C. I. 1643 (*Oryza sativa*), May 27 to Sept. 23	151	248.4	133.5	538
	152	253.1	141.2	558
	153	232.5	127.4	548
	154	168.9	90.5	536
	155	194.0	94.8	488
	156	225.6	100.0	445
Mean				519±13
1913.				
Rice, Honduras, C. I. 1643, June 12 to Sept. 16	157	276.7	218.2	790
	158	261.7	211.5	809
	159	230.2	176.9	768
	160	274.8	186.6	680
	161	294.8	204.0	692
	162	298.7	215.8	722
Mean				744±17

FLAX

Flax was included in the water-requirement measurements at Akron for the first time in 1913. Its water requirement was found to be very high, 905±25 based on dry matter and 2,835±52 when based on seed production. It will thus be seen to have a water requirement as high or higher than any of the legumes tested in 1913. This is in accord with the measurements made by Leather (1911, p. 270) in India, in which flax was exceeded in water requirement only by chick-peas and rice. At Akron in 1913 flax required 22 per cent more water than rice. The detailed results are given in Table X.

TABLE X.—*Water requirement of flax at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Flax, North Dakota, No. 155 (*Linum usitatissimum*), June 3 to Sept. 1	127	189. 0	64. 9	184. 8	34	2, 845	978
	128	154. 7	53. 0	143. 4	34	2, 704	927
	129	209. 3	77. 2	210. 6	37	2, 728	1, 006
	130	93. 0	23. 9	76. 3	26	3, 190	811
	131	116. 7	32. 5	93. 9	28	2, 886	804
	132	187. 8	63. 7	169. 2	34	2, 658	902
Mean						2, 835±52	905±25

SUGAR BEETS

The water requirement of the sugar beet was again measured at Akron in 1912. The ratio 321±8 was obtained on the basis of total dry matter and 524±23 on the basis of the dry root (Table XI). This is about 15 per cent below the 1911 value, a reduction in water requirement similar to that shown by the other crops tested during the two seasons. The sugar beet is an efficient plant in the use of water, being the equal of the corn group in this respect.

TABLE XI.—*Water requirement of sugar beets at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Roots.	Water.	Roots.	Water requirement based on—	
						Dry roots.	Total dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Sugar beet (*Beta vulgaris*), June 9 to Oct. 12	169	257. 4	189. 7	76. 0	74	401	295
	170	175. 0	93. 6	55. 7	53	595	318
	171	173. 3	100. 0	49. 6	58	496	286
	172	163. 6	107. 3	52. 5	66	489	321
	173	196. 8	123. 0	68. 7	63	558	349
	174	164. 5	97. 7	58. 9	60	603	358
Mean						524±23	321±8

COTTON

Cotton was tested at Akron for the first time in 1912. Numerous bolls set, though none opened. The plants grew slowly during the first part of the season, owing probably to the cool nights. The observed water-requirement ratio was 488±14 (Table XII).

TABLE XII.—*Water requirement of cotton at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1912.		*Grams.*	*Kilos.*	
Cotton, Triumph (*Gossypium hirsutum*), July 19 to Sept. 21	181	38.9	19.2	494
	182	32.0	18.5	578
	183	67.4	27.1	402
	184	61.4	28.2	459
	185	51.6	25.2	488
	186	62.4	31.5	505
Mean				488±14
1913.				
Cotton, Triumph, May 29 to Sept. 16	163	237.5	172.4	726
	164	184.3	115.6	627
	165	247.4	166.1	671
	166	249.6	160.1	642
	167	161.4	106.4	660
	168	187.0	115.4	617
Mean				657±11

The same variety was also included in the 1913 measurements. (Pl. VII, fig. 1.) The planting was made earlier, and a much larger growth was obtained. The water requirement was 657±11, or about one-third higher than in 1912. In this connection it should be stated that at Akron cotton is far north of its natural range, which may have increased its relative water requirement.

CORN AND TEOSINTE

Six varieties of corn (*Zea mays*) were tested at Akron in 1912 (Pl. VII, fig. 5). Three of these varieties, Northwestern Dent (Pl. IV, fig. 1), Iowa Silvermine, and Esperanza, had also been used in the 1911 experiments. The three new varieties were furnished by Mr. G. N. Collins, of the Bureau of Plant Industry, and represent widely different strains. The Hopi variety (Pl. IV, fig. 2) is grown by the Hopi Indians in northwestern New Mexico (Collins, 1914); China White is a variety from near Shanghai, China; while Laguna was originally from the State of Chihuahua, Mexico. The water requirement of each variety tested in 1912, based on the production of dry matter, is as follows:

Variety of corn	Water requirement
Esperanza	239±3
Northwestern Dent	280±10
Hopi	285±7
Laguna	295±6
Iowa Silvermine	302±7
China White	315±7

The Esperanza, as in 1911, leads all the varieties, so far as efficiency in the production of dry matter is concerned, and ranks with the sor-

ghums in this respect. The differences exhibited by the remaining varieties are without significance when the limitations imposed by the probable errors are considered, although the quick-maturing Northwestern Dent and Hopi varieties appear to be slightly more efficient than the others. The detailed data are given in Table XIII. The pollination was not adequate to give representative grain yields.

Five varieties of corn and one of teosinte were included in the 1913 measurements. The water requirement of each variety, based on the production of dry matter, is as follows:

Variety of corn or teosinte	Water requirement
Indian Flint corn	342±5
Hopi corn	350±8
Teosinte, Durango	390±11
Northwestern Dent corn	399±12
Bloody Butcher corn	405±7
China White corn	415±4

The most efficient varieties were the Indian Flint (Pl. VI, fig. 5), a small variety grown by the Indians of northern Michigan, and the Hopi, another dwarf Indian variety. Teosinte, Northwestern Dent corn, and Bloody Butcher, a local variety of corn grown near Wray, Colo., showed only slight differences. The China White, as in 1912, proved to be the least efficient of all the varieties tested, having a water requirement 20 per cent above that of the Indian varieties.

In 1912 the water requirement of the Northwestern Dent corn was in practical agreement with that of the Hopi, while in 1913 the Hopi gave a considerable lower value. The China White required 32 per cent more water in 1913 than in 1912; the Northwestern Dent, 42 per cent; and the Hopi, 23 per cent.

The water requirement of certain corn hybrids was also measured at Akron in 1912 and 1913. The mean water requirement of each strain has been included in the tables in the summary (Tables XXIX to XXXII).

TABLE XIII.—*Water requirement of different varieties of corn and teosinte at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Corn, Northwestern Dent (*Zea mays*), June 9 to Sept. 16	277	299.0	18.1	102.6	6	....	343
	278	344.2	53.9	100.4	16	....	292
	279	368.5	66.1	105.5	18	....	286
	280	649.0	234.4	161.1	36	....	248
	281	440.0	101.5	111.2	23	....	253
	282	491.0	117.1	126.1	24	....	257
Mean	......	......	......	......	......	....	280±10

TABLE XIII.—*Water requirement of different varieties of corn and teosinte at Akron, Colo., in 1912 and 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Corn, Iowa Silvermine (*Zea mays*), June 8 to Sept. 26	283	596.0	....	167.9	....	....	282
	284	403.7	....	129.9	....	....	322
	285	399.7	....	133.4	....	....	334
	286	441.5	....	129.6	....	....	294
	287	477.0	....	135.6	....	....	284
	288	437.2	....	128.9	....	....	295
Mean	......	......	......	......	......	....	302±7
Corn, Hopi (*Zea mays*), June 12 to Sept. 26	295	433.0	....	132.7	....	....	307
	296	519.5	....	140.3	....	....	270
	297	516.8	....	131.1	....	....	254
	298	415.8	....	113.4	....	....	273
	299	330.9	....	100.2	....	....	303
	300	364.7	....	111.3	....	....	305
Mean	......	......	......	......	......	....	285±7
Corn, China White (*Zea mays*), June 12 to Sept. 26	265	243.5	....	84.3	....	....	346
	266	577.0	....	184.6	....	....	320
	267	319.0	....	97.1	....	....	304
	268	524.5	....	173.9	....	....	331
	269	660.9	....	179.6	....	....	272
	270	401.5	....	126.1	....	....	314
Mean	......	......	......	......	......	....	315±7
Corn, Laguna (*Zea mays*), July 2 to Sept. 26	289	376.6	....	112.4	....	....	298
	290	261.2	....	83.8	....	....	321
	291	268.9	....	84.0	....	....	313
	292	448.1	....	124.4	....	....	278
	293	457.4	....	127.8	....	....	279
	294	429.2	....	119.4	....	....	278
Mean	......	......	......	......	......	....	295±6
Corn, Esperanza (*Zea mays*), June 12 to Sept. 26	301	492.3	....	114.3	....	....	232
	302	574.7	....	133.7	....	....	233
	303	563.7	....	141.7	....	....	252
	304	510.7	....	122.7	....	....	240
Mean	......	......	......	......	......	....	239±3
1913.							
Corn, Bloody Butcher (*Zea mays*), June 7 to Sept. 13	247	411.5	....	174.1	....	....	423
	248	485.4	....	201.5	....	....	415
	249	456.6	....	188.6	....	....	413
	250	501.9	....	193.0	....	....	385
	251	499.4	....	183.6	....	....	368
	252	456.8	....	195.4	....	....	428
Mean	......	......	......	......	......	....	405±7
Corn, Indian Flint (*Zea mays*), June 7 to Aug. 27	253	333.4	123.4	114.9	37	931	345
	254	397.9	163.3	130.5	41	800	328
	255	380.6	161.7	120.6	42	746	317
	256	292.0	101.6	108.2	35	1,064	370
	257	335.1	135.2	118.7	40	878	354
	258	380.3	182.6	128.6	48	704	338
Mean	......	......	......	......	......	854±39	342±5

TABLE XIII.—*Water requirement of different varieties of corn and teosinte at Akron, Colo., in 1912 and 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Corn, Northwestern Dent (*Zea mays*), June 7 to Sept. 6	283	351.2	......	153.7	......	....	436
	284	392.3	131.6	142.9	34	1,086	364
	285	336.6	......	136.6	......	....	406
	286	285.9	......	128.7	......	....	451
	287	389.9	117.5	141.4	30	1,203	363
	288	382.0	100.0	143.4	26	1,434	375
Mean	......	......	......	......	......	1,241±77	399±12
Corn, Hopi (*Zea mays*), June 14 to Sept. 16	313	346.7	......	118.8	......	....	343
	314	400.0	......	135.8	......	....	340
	315	472.5	......	170.2	......	....	360
	316	417.1	......	147.0	......	....	352
	317	405.3	......	163.4	......	....	403
	318	619.6	......	185.4	......	....	300
Mean	......	......	......	......	......	....	350 ±8
Corn, China White (*Zea mays*), June 7 to Sept. 16	301	554.9	......	228.2	......	....	411
	302	487.5	......	210.4	......	....	432
	303	492.6	......	202.3	......	....	411
	304	589.2	......	228.1	......	....	387
	305	478.7	......	198.7	......	....	415
	306	523.1	......	226.6	......	....	433
Mean	......	......	......	......	......	....	415 ±4
Teosinte, Durango (*Euchlaena mexicana*), June 14 to Sept. 16	289	616.4	......	234.7	......	....	380
	290	534.5	......	211.6	......	....	396
	291	624.5	......	194.0	......	....	310
	292	567.3	......	231.5	......	....	408
	293	520.0	......	214.4	......	....	412
	294	421.4	......	183.2	......	....	435
Mean	......	......	......	......	......	....	390±11

SORGHUM

The investigation of the water requirement of the sorghums (Table XIV) is of special interest, owing to the marked efficiency exhibited by this group of plants in the use of water. The eight varieties grown at Akron in 1912, together with the water requirement based on the production of dry matter, follow:

Variety of sorghum	Water requirement
Brown kaoliang	223±1
Red Amber	237±4
Minnesota Amber	239±2
Milo	249±3
White durra	255±3
Blackhull kafir	259±5
Dwarf milo	273±4
Sudan grass	359±2

The Brown kaoliang gave the lowest water requirement. Red Amber and Minnesota Amber, forage varieties of sorghum (Pl. IV, figs. 4 and 5), gave practically the same ratio, which is but slightly higher than Brown kaoliang.

TABLE XIV.—*Water requirement of different sorghums at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Red Amber, S. P. I. 17543 (*Andropogon sorghum*), June 9 to Sept. 27	253	400.5	43.8	103.1	11	2,351	258
	254	541.7	41.5	133.8	8	3,221	247
	255	592.0	58.1	135.5	10	2,331	229
	256	660.5	95.4	144.8	14	1,518	219
	257	564.0	44.3	135.1	8	3,050	240
	258	714.2	93.5	161.0	13	1,722	226
Mean						2,366±194	237±4
Minnesota Amber, A. D. I. 341-13 (*Andropogon sorghum*), June 9 to Sept. 26	247	666.6	272.6	151.2	41	554	227
	248	370.6	139.9	89.6	38	645	242
	249	543.0	218.4	128.1	40	586	236
	250	461.3	168.1	110.6	37	658	240
	251	456.6	195.7	110.3	43	564	242
	252	425.3	163.3	103.6	38	634	244
Mean						607±15	239±2
Milo, Dwarf, S. P. I. 24970 (*Andropogon sorghum*), June 9 to Sept. 27	217	434.5	83.0	115.1	19	1,387	265
	218	370.2	79.9	102.0	22	1,276	275
	219	334.3	55.3	90.6	17	1,638	271
	220	403.7	78.5	105.7	19	1,347	262
	221	420.1	84.5	110.2	20	1,304	262
	222	301.2	64.5	91.8	21	1,422	305
Mean						1,396±34	273±4
Milo, S. P. I. 24960 (*Andropogon sorghum*), June 9 to Sept. 27	223	475.4	60.0	125.6	13	2,092	264
	224	440.4	85.7	103.7	19	1,210	235
	225	472.5	77.9	114.5	17	1,470	242
	226	488.9	114.0	123.3	23	1,081	252
	227	499.9	116.0	123.0	23	1,060	246
	228	509.9	79.6	128.8	16	1,618	253
Mean						1,422±115	249±3
Durra, White, S. P. I. 24997 (*Andropogon sorghum*), June 9 to Sept. 26	235	506.9	138.7	129.3	27	925	255
	236	568.9	142.7	142.1	25	996	250
	237	432.9	85.6	106.7	20	1,246	247
	238	384.6	63.5	105.1	17	1,656	273
	239	406.2	78.1	99.4	19	1,273	245
	240	449.6	108.6	115.9	24	1,067	258
Mean						1,194±75	255±3
Kaoliang, Brown, S. P. I. 24993 (*Andropogon sorghum*), June 9 to Sept. 26	241	588.9	144.8	134.0	25	925	228
	242	411.1	108.8	94.8	26	870	230
	243	548.9	125.3	120.5	23	962	220
	244	556.0	126.0	123.8	23	982	223
	245	526.0	171.0	116.8	33	683	222
	246	571.8	108.7	123.9	19	1,140	217
Mean						927±38	223±1

TABLE XIV.—*Water requirement of different sorghums at Akron, Colo., in 1912 and 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Kafir, Blackhull, S. P. I. 24975 (*Andropogon sorghum*), June 9 to Sept. 27	229	247.0		72.1			292
	230	409.1		108.4			265
	231	494.5		119.3			241
	232	413.0		101.8			246
	233	363.3		91.9			253
	234	377.1		97.4			258
Mean							259±5
Sudan grass, S. P. I. 25017 (*Andropogon sorghum aethiopicus*), first crop, May 28 to July 26	211	190.6		60.8			319
	212	209.4		65.8			314
	213	181.8		59.4			326
	214	205.8		63.4			308
	215	215.9		63.8			296
	216	222.6		68.6			308
Mean							312±3
Sudan grass, S. P. I. 25017, second crop, July 26 to Sept. 6	211	106.7		46.1			432
	212	94.0		43.5			463
	213	95.6		44.6			467
	214	106.5		45.9			431
	215	91.0		42.9			472
	216	88.0		43.0			489
Mean							459±7
Sudan grass, S. P. I. 25017, combined crop, May 28 to Sept. 6	211	297.3		106.9			359
	212	303.4		109.3			360
	213	277.4		104.0			375
	214	312.3		109.3			350
	215	306.9		106.7			348
	216	310.6		111.6			360
Mean							359±2
1913.							
Sorghum, Minnesota Amber, A. D. I. 341-13 (*Andropogon sorghum*), June 14 to Sept. 15	265	557.8	213.0	164.5	38	772	295
	266	585.0	256.9	181.4	44	706	310
	267	591.8	235.4	177.4	40	754	299
	268	677.5	263.0	203.1	39	773	301
	269	577.9	204.0	167.5	35	821	290
	270	643.0	150.7	189.7	23		295
Mean						765±12	298±2
Sorghum, Red Amber, S. P. I. 17543 (*Andropogon sorghum*), June 7 to Sept. 15	277	689.7	209.4	200.5	30	958	291
	278	670.7	190.6	196.0	28	1,028	292
	279	636.2	160.2	187.9	25	1,172	295
	280	644.1	165.6	193.9	26	1,170	301
	281	682.3	187.4	200.5	23	1,070	294
	282	749.7	187.8	225.2	25	1,199	301
Mean						1,100±31	296±1

The least efficient variety tested in the sorghum group is Sudan grass (Pl. V, fig. 1), a forage plant which has recently received considerable attention in the southern Great Plains. Only one year's measurements are available for Sudan grass, but the results so far indicate that it is not the equal of other well-known varieties of sorghum in efficiency in the use of water. Sudan grass required 40 per cent more water than Brown kaoliang for the production of the first crop. The second crop was light at Akron and had a much higher water requirement. On the basis of the two cuttings combined, the water requirement of Sudan grass was 62 per cent higher than Brown kaoliang. As a forage crop, however, the shorter and more slender stalks of Sudan grass may offset the disadvantage of its higher water requirement.

In the production of grain the Minnesota Amber[1] variety gave the lowest water requirement ratio so far recorded for a sorghum crop, viz, 607 ± 15. The Minnesota Amber produced a pound of grain at Akron in 1912 with less water than was required by alfalfa in the production of a pound of hay. The high water requirement for grain production in Red Amber sorghum, Dwarf milo, milo, and White durra (Pl. IV, fig. 3) is largely due to an attack of aphids, which caused many of the flowers to fail to produce seed. The parasites were killed by spraying early enough to prevent any serious reduction in total growth.

The 1913 water requirement measurements of sorghum were confined to two varieties, Red Amber and Minnesota Amber, both of which were included in the 1912 measurements. The two varieties gave in 1913 practically identical water-requirement ratios—namely, 296 ± 1 and 298 ± 2. The results from individual pots were in excellent agreement as indicated by the small probable error. A similar agreement was observed in 1912. Each variety in 1913 showed an increase of 25 per cent in the water requirement as compared with 1912.

A series of water-requirement measurements were made at Amarillo, Tex., in 1913, for the purpose of determining the influence of climatic environment on the water requirement. These measurements also included a number of sorghum varieties, the water requirement of which had never before been determined. Plants have a higher water requirement at Amarillo than at Akron, so that measurements of different plants at the two stations are not directly comparable. The water requirement of Red Amber and Minnesota Amber sorghum was measured at both stations in 1913, and the ratio of these measurements affords a means for reducing the Amarillo values to the basis of the Akron measurements. The mean water requirement of these two varieties at Akron was 85 per cent of that at Amarillo. The Amarillo water-requirement measurements as given in Table XVI have been reduced accordingly

[1] This variety was represented by a strain selected for its drought resistance by Mr. A. C. Dillman, of the Office of Alkali and Drought Resistant Plant Investigations.

for comparison with the Akron measurements. The computed values for Akron are given in Table XV.

TABLE XV.—*Observed water requirement of varieties of sorghum at Amarillo, Tex., and computed water requirement for Akron, Colo., in 1913*

Variety.	Observed water requirement at Amarillo.	Computed water requirement for Akron.
Dwarf Blackhull kafir	335±3	285±3
White kafir	349±4	297±4
Early Blackhull kafir	356±15	302±13
White milo	373±3	317±3
Kafir×durra	378±5	321±5
Feterita	380±4	323±4

It will be noted (Table XV) that Dwarf Blackhull kafir and Minnesota Amber sorghum were the most efficient in the use of water of the eight varieties of sorghum tested at Amarillo in 1913. The least efficient was feterita. The kafir×durra hybrid had practically the same water requirement as feterita. The latter has been extensively featured recently as a drought-resistant crop particularly adapted to the Southwest. It does not appear, however, that its drought-resistant qualities are ascribable to an efficiency in the use of water, this variety being the highest in water requirement of all the sorghums tested at Amarillo in 1913. Vinall and Ball (1913, p. 27) have suggested that the success of feterita during recent dry years has been due to a thin stand resulting in part from poor germination. When grown under identical conditions as to stand, it showed no greater drought resistance than milo or kafir.

TABLE XVI.—*Water requirement of sorghum at Amarillo, Tex., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Sorghum, Red Amber, S. P. I. 17543 (*Andropogon sorghum*), May 15 to Aug. 20	43	717.4	159.3	267.8	22	1,680	373
	44	682.2	137.9	262.4	20	1,904	385
	45	723.6	205.9	268.0	28	1,302	371
	46	701.9	117.4	256.2	17	2,182	365
	47	741.3	197.0	270.7	27	1,374	365
	48	768.7	208.7	272.9	27	1,306	355
Mean						1,625±112	369±3
Sorghum, Minnesota Amber, A. D. I. 341–13 (*Andropogon sorghum*), May 15 to Aug. 8	49	590.2	233.2	196.2	39	841	332
	50	588.3	295.4	196.6	50	666	334
	51	612.7	291.9	199.7	48	685	326
	52	646.0	308.9	208.1	48	674	322
	53	577.1	264.5	201.0	46	760	348
	54	649.5	288.9	211.1	44	731	325
Mean						726±19	331±3

TABLE XVI.—*Water requirement of sorghum at Amarillo, Tex., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Milo, White, C. I. 365 (*Andropogon sorghum*), June 7 to Aug. 22	61	464.5	80.4	173.5	17	2,159	374
	62	481.1	107.3	166.3	22	1,550	346
	63	453.0	75.6	171.9	17	2,272	380
	64	470.0	108.4	176.4	23	1,626	375
	65	449.3	79.6	170.9	18	2,148	380
	66	471.1	112.2	179.6	24	1,601	381
Mean						1,893±113	373±3
Kafir, Early Blackhull, C. I. 472 (*Andropogon sorghum*), June 11 to Sept. 16	67	587.4	182.7	198.6	31	1,087	338
	68	577.8	178.6	207.3	31	1,160	359
	69	599.4	235.7	197.6	39	839	330
	70	530.6	193.4	169.8	36	878	320
	71	440.2	220.2	206.9	50	940	470
	72	603.4	199.8	192.1	33	962	319
Mean						978±37	356±15
Kafir, Dwarf Blackhull, C. I. 340 (*Andropogon sorghum*), June 11 to Sept. 16	73	592.5	254.0	190.8	43	752	322
	74	621.6	276.1	200.0	44	724	322
	75	562.7	205.2	191.5	36	934	340
	76	586.7	260.0	197.9	44	761	337
	77	544.8	195.6	191.7	36	980	352
	78	559.3	152.7	187.0	27	1,223	334
Mean						896±57	335±3
Kafir, White, C. I. 370 (*Andropogon sorghum*), June 11 to Sept. 22	79	555.3	185.9	201.7	33	1,086	363
	80	546.2	106.4	200.1	19	[a] 1,882	366
	81	571.8	210.8	198.5	37	942	347
	82	584.2	248.7	198.0	43	796	339
	83	569.6	221.0	194.3	39	879	341
	84	579.6	228.3	195.9	39	858	338
Mean						912±34	349±4
Kafir×durra, hybrid 198-15-3 (*Andropogon sorghum*) June 11 to Sept. 22	85	552.0	226.5	200.1	41	884	363
	86	538.4	215.3	193.1	40	898	358
	87	539.7	217.6	199.1	40	916	369
	88	515.0	206.6	194.7	40	942	378
	89	510.7	179.5	197.1	35	1,098	386
	90	471.5	158.1	194.0	23	1,226	411
Mean						994±42	378±5
Feterita, C. I. 182 (*Andropogon sorghum*) June 11 to Sept. 18	91	547.8	181.3	212.1	33	1,170	387
	92	585.4	235.8	216.0	40	916	369
	93	619.3	256.9	226.9	41	884	366
	94	531.1	210.9	206.1	41	979	388
	95	562.8	210.2	208.5	37	992	370
	96	512.0	191.3	203.8	37	1,064	398
Mean						1,001±29	380±4

[a] Omitted in computing the mean.

MILLET AND PROSO

These plants are remarkable in that they outrank all others so far tested as regards efficiency in the use of water (Table XVII). The four varieties grown at Akron in 1912 gave the following water requirement, based on the production of dry matter:

Variety of millet or proso	Water requirement
Kursk millet	187±2
Voronezh proso	206±1
Tambov proso	208±1
German millet	248±7

Kursk millet (Pl. V, fig. 3) represented by a strain developed by Mr. A. C. Dillman, of the Office of Alkali and Drought Resistant Plant Investigations, gave the lowest water requirement so far recorded for any crop at Akron. The two prosos, Tambov and Voronezh (Pl. V, fig. 2), have a water requirement about 10 per cent higher than the Kursk, while German millet is 33 per cent higher than the Kursk. Aside from the German millet, all of the varieties tested have a water requirement distinctly below the best of the sorghums, the group ranking next in efficiency.

TABLE XVII.—*Water requirement of different millets and prosos at Akron, Colo., in 1912 and 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Millet, Kursk, S. P. I. 34771 (*Chaetochloa italica*), June 9 to Aug. 20	205	190.7	66.1	36.7	35	555	192
	206	320.0	119.1	58.9	37	494	184
	207	241.7	102.6	44.1	42	430	182
	208	192.5	78.4	36.1	41	461	188
	209	178.9	66.5	32.6	37	490	182
	210	332.6	139.3	65.0	42	467	195
Mean						483±11	187±2
Millet, German, S. P. I. 26845 (*Chaetochloa italica*), July 2 to Sept. 23	187	115.1		27.3			237
	188	202.6		46.7			231
	189	140.0		33.9			242
	190	350.3		82.4			235
	191	92.5		22.4			242
	192	80.5		24.2			301
Mean							248±7
Proso, Tambov, S. D. 366, Akron, 366-1-10 (*Panicum miliaceum*), June 8 to Aug. 12	193	255.3	111.0	54.8	43	494	214
	194	342.9	162.4	68.0	47	419	198
	195	190.0	80.7	39.7	42	492	209
	196	317.6	140.2	66.5	44	474	209
	197	336.2	142.8	70.1	43	491	208
	198	282.7	112.6	58.9	40	523	208
Mean						482±9	208±1

TABLE XVII.—*Water requirement of different millets and prosos at Akron, Colo., in 1912 and 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Proso, Voronezh, C. I. 16 (*Panicum miliaceum*), June 5 to Aug. 20	199	238.7	114.2	48.9	48	428	205
	200	296.1	143.7	61.2	48	426	207
	201	281.9	135.6	56.8	48	419	201
	202	298.5	149.5	59.9	50	401	201
	203	256.1	119.4	53.7	47	450	210
	204	273.0	133.2	57.0	49	428	209
Mean	......	......	......	......	......	425±4	206±1
1913.							
Kursk, S. P. I. 34771 (*Chaetochloa italica*), June 14 to Aug. 26	259	174.8	37.1	48.9	21	1,318	280
	260	281.7	76.1	80.7	27	1,060	286
	261	175.4	71.6	50.5	41	705	288
	262	183.3	31.9	51.3	17	....	280
	263	250.6	33.4	66.3	13	....	265
	264	201.8	74.0	63.5	37	858	315
Mean	......	......	......	......	......	......	286±4

In grain production the millets make a remarkable showing, the prosos leading in this respect. Measurements of the water requirement of the three varieties, based on grain production, gave the following results:

Variety of millet or proso	Water requirement
Voronezh proso	425±4
Tambov proso	482±9
Kursk millet	483±11

Voronezh proso, according to these figures, is able to produce nearly 2 pounds of grain with the water required for the production of 1 pound of alfalfa hay.

Kursk millet was also included in the 1913 measurements. Its water requirement was 286±4, or 53 per cent higher than in 1912. Many of the plants were broken by a high wind shortly before harvest, which greatly reduced the grain yield. The mean water requirement, based on grain production, has consequently been omitted.

LEGUMES

The legumes tested at Akron in 1912 included sweet clover, chick-pea, and two strains of Grimm alfalfa, one being a selected strain (Pl. V, figs. 4 and 5) developed by Mr. A. C. Dillman. Both the alfalfa and the sweet clover showed a marked reduction in water requirement compared with the results obtained in 1911. Three cuttings were made in the case of each crop, but the plants were not mature at the time

the last cutting was made. The following values (Table XVIII) were obtained for the water-requirement ratio:

TABLE XVIII.—*Summary of water-requirement measurements of legumes at Akron, Colo., in 1912*

Crop.	Cutting.			
	First.	Second.	Third.	Combined.
Alfalfa, Grimm	592±13	790±10	506±5	659±6
Alfalfa, Grimm, A. D. I. selection	600±17	853±13	421±10	657±11
Clover, sweet	547±12	677±14	598±18	638±4
Chick-pea				510±14

The two alfalfas and the sweet clover were planted on the same day, and the crops in each instance were all cut on the same day, so that the results in the Table XVIII are comparable. The A. D. I. strain of Grimm alfalfa gave a slightly higher ratio than the unselected Grimm during the second period, but lower during the third period, when it made a better growth. (See "Dry matter," column 3, Table XIX.) Sweet clover, as in 1911, proved somewhat more efficient than alfalfa during the first and second periods. During the third period sweet clover was less efficient than alfalfa.

The chick-pea proved the most efficient of the legumes tested. Its growth period does not coincide with that of the other legumes, but approximates a combination of the first and second periods. (See Table XIX.) It thus appears to be distinctly more efficient in the use of water than either alfalfa or sweet clover. Chick-pea has, however, a relatively high water requirement compared with the small grain crops, which is in accord with Leather's measurements (Leather, 1910, p. 156).

TABLE XIX.—*Water requirement of different legumes at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Alfalfa, Grimm, S. P. I. 25695 (*Medicago sativa*), first crop, May 23 to July 26	127	110.3		60.3			548
	128	118.5		77.3			652
	129	141.4		86.1			609
	130	124.2		74.8			602
	131	112.4		59.9			533
	132	156.8		95.0			606
Mean							592±13
Alfalfa, Grimm, second crop, July 26 to Sept. 6	127	141.2		112.4			796
	128	112.5		97.0			862
	129	129.1		100.8			781
	130	125.0		98.8			790
	131	131.2		100.1			763
	132	168.3		125.8			748
Mean							790±10

TABLE XIX.—*Water requirement of different legumes at Akron, Colo., in 1912*—Contd.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Alfalfa, Grimm, third crop, Sept. 6 to Nov. 4	127	68. 2		36. 5			536
	128	65. 7		32. 4			493
	129	59. 9		29. 6			494
	130	51. 9		26. 9			518
	131	48. 2		24. 4			506
	132	60. 2		29. 3			487
Mean							506±5
Alfalfa, Grimm, combined crop, May 23 to Nov. 4	127	319. 7		209. 2			654
	128	296. 7		206. 7			697
	129	330. 4		216. 5			656
	130	301. 1		200. 5			666
	131	291. 8		184. 4			632
	132	385. 3		250. 1			649
Mean							659±6
Alfalfa, Grimm A. D. I. E-23-20-52, first crop, May 24 to July 26	133	131. 6		89. 6			680
	134	121. 4		73. 9			609
	135	141. 0		82. 4			584
	136	140. 6		72. 5			516
	137	141. 4		79. 8			564
	138	118. 0		76. 6			649
Mean							600±17
Alfalfa, Grimm, second crop, July 26 to Sept. 6	133	131. 7		118. 8			902
	134	110. 0		93. 0			845
	135	138. 6		112. 4			810
	136	133. 3		115. 8			870
	137	135. 2		108. 1			800
	138	120. 2		107. 4			893
Mean							853±13
Alfalfa, Grimm, third crop, Sept. 6 to Nov. 4	133	73. 7		35. 4			479
	134	64. 7		28. 1			434
	135	80. 7		32. 4			401
	136	82. 0		32. 0			390
	137	83. 8		36. 1			431
	138	79. 5		31. 1			391
Mean							421±10
Alfalfa, Grimm, combined crop, May 24 to Nov. 4	133	337. 0		243. 8			724
	134	296. 1		195. 0			658
	135	359. 6		227. 2			632
	136	355. 9		220. 3			620
	137	360. 4		224. 4			627
	138	317. 7		215. 1			678
Mean							657±11
Clover, sweet, S. P. I. 21216(*Melilotus alba*), first crop, May 23 to July 26	121	108. 2		61. 4			568
	122	61. 5		36. 8			598
	123	64. 4		33. 6			522
	124	69. 5		37. 7			542
	125	137. 0		68. 9			503
Mean							547±12

TABLE XIX.—*Water requirement of different legumes at Akron, Colo., in 1912*—Contd.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1912.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Clover, sweet, second crop, July 26 to Sept. 6	121	155.3	......	111.6	......	....	719
	122	130.5	......	87.5	......	....	670
	123	103.8	......	74.7	......	....	720
	124	143.9	......	94.5	......	....	657
	125	149.0	......	92.3	......	....	620
Mean	......	......	......	......	......	....	677±14
Clover, sweet, third crop, Sept. 6 to Nov. 7	121	23.9	......	12.5	......	....	522
	122	19.4	......	12.0	......	....	619
	123	15.3	......	9.3	......	....	608
	124	14.8	......	9.5	......	....	642
Mean	......	......	......	......	......	....	598±18
Clover, sweet, combined crop, May 23 to Nov. 7	121	287.4	......	185.5	......	....	645
	122	211.4	......	136.3	......	....	645
	123	183.5	......	117.6	......	....	641
	124	228.3	......	141.7	......	....	621
Mean	......	......	......	......	......	....	638±4
Chick-pea, S. P. I. 24322 (*Cicer arietinum*), June 3 to Aug. 30	157	239.9	97.0	138.0	40	1,423	576
	158	275.5	126.3	129.1	46	1,022	469
	159	238.3	85.0	127.1	36	1,495	533
	160	181.1	47.2	96.0	26	2,032	530
	161	272.0	120.1	129.4	44	1,077	476
	162	227.0	104.5	108.6	46	1,039	478
Mean	......	......	......	......	......	1,348±114	510±14

A number of different legumes were included in the 1913 water-requirement measurements at Akron (Table XX). On the basis of dry matter produced, the results obtained are as follows:

Kind of legume	Water requirement
Cowpea	571±3
Soy bean	672±9
Navy bean	682±4
Peruvian alfalfa	651±12
Hairy vetch	690±8
Horse bean, S. P. I. 25645	772±11
Mexican bean	773±8
Canada pea	775±5
Horse bean, S. P. I. 15429	780±19
Red clover	789±9
Crimson clover	805±8
Wild soy bean	815±25
Grimm alfalfa	834±8
Purple vetch	935±9

Cowpea (Pl. VI, fig. 1) was the most efficient of the cultivated legumes. The least efficient was purple vetch. The water requirement of the first crop of hairy vetch (Pl. VI, fig. 2) was 9 per cent less than for purple vetch, the period of growth being the same for both varieties. Some of the pots of hairy vetch produced a good second growth, but none of the pots of purple vetch were able to survive the first cutting. The water requirement of the combined crops of hairy vetch was 690±8, or about three-fourths that of purple vetch. Of the soy beans (Pl. VI, fig. 3) the wild required 21 per cent more water than the cultivated variety, which in turn required 18 per cent more water than cowpea. (See Table XX.)

TABLE XX.—*Water requirement of legumes at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Alfalfa, Grimm, E-23-20-52 (*Medicago sativa*), first crop, June 7 to July 18	55	120. 8	......	104. 1	......	....	862
	56	110. 0	......	91. 7	......	....	834
	57	99. 0	......	72. 3	......	....	730
	58	114. 8	......	89. 8	......	....	782
	59	114. 9	......	94. 0	......	....	818
	60	110. 5	......	86. 9	......	....	786
	61	98. 0	......	80. 8	......	....	824
	62	104. 5	......	79. 5	......	....	760
	63	104. 7	......	87. 1	......	....	832
	64	97. 5	......	84. 8	......	....	870
	65	96. 5	......	73. 7	......	....	764
	66	117. 6	......	92. 1	......	....	783
Mean	......	......	......	......	......	....	804±9
Alfalfa, Grimm, second crop, July 18 to Aug. 26	55	115. 8	......	106. 7	......	....	922
	56	106. 4	......	95. 7	......	....	900
	57	108. 7	......	89. 7	......	....	825
	58	114. 8	......	96. 3	......	....	838
	59	101. 1	......	95. 1	......	....	940
	60	95. 8	......	84. 4	......	....	881
	61	102. 7	......	88. 9	......	....	866
	62	104. 1	......	91. 9	......	....	882
	63	114. 0	......	98. 2	......	....	861
	64	85. 7	......	80. 3	......	....	937
	65	98. 9	......	86. 1	......	....	871
	66	109. 6	......	89. 1	......	....	812
Mean	......	......	......	......	......	....	878±8
Alfalfa, Grimm, third crop, Aug. 26 to Oct. 23	55	89. 3	......	77. 5	......	....	868
	56	82. 2	......	70. 4	......	....	856
	57	73. 8	......	55. 5	......	....	752
	58	76. 6	......	59. 1	......	....	771
	59	81. 9	......	70. 4	......	....	860
	60	79. 3	......	63. 0	......	....	794
	61	85. 5	......	63. 3	......	....	740
	62	76. 5	......	60. 4	......	....	790
	63	88. 9	......	76. 8	......	....	864
	64	66. 9	......	56. 4	......	....	843
	65	71. 3	......	61. 7	......	....	866
	66	87. 6	......	70. 7	......	....	807
Mean	......	......	......	......	......	....	818±11

TABLE XX.—*Water requirement of legumes at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Alfalfa, Grimm, combined crop, June 5 to Oct. 23	55	325.9	......	288.3	......	....	886
	56	298.6	......	257.8	......	....	864
	57	281.5	......	217.5	......	....	773
	58	306.2	......	245.2	......	....	801
	59	297.9	......	259.5	......	....	871
	60	285.6	......	234.3	......	....	821
	61	286.2	......	233.0	......	....	814
	62	285.1	......	231.8	......	....	813
	63	307.6	......	262.1	......	....	853
	64	250.1	......	221.5	......	....	886
	65	266.7	......	221.5	......	....	831
	66	314.8	......	251.9	......	....	800
Mean	......	......	......	......	......	....	834±8
Alfalfa, Peruvian, S. P. I. 30203 (*Medicago sativa*), first crop, June 7 to July 19	97	41.5	......	26.3	......	....	634
	98	70.3	......	45.5	......	....	648
	99	66.0	......	38.9	......	....	590
	100	45.0	......	27.3	......	....	606
	101	78.8	......	54.8	......	....	695
	102	87.9	......	64.4	......	....	733
Mean	......	......	......	......	......	....	651±16
Alfalfa, Peruvian, second crop, July 19 to Aug. 26	97	62.0	......	42.5	......	....	685
	98	104.5	......	73.3	......	....	701
	99	91.4	......	63.9	......	....	699
	100	69.9	......	47.0	......	....	672
	101	88.4	......	69.5	......	....	786
	102	102.3	......	82.5	......	....	806
Mean	......	......	......	......	......	....	725±18
Alfalfa, Peruvian, third crop, Aug. 26 to Oct. 23	97	63.6	......	39.9	......	....	627
	98	99.2	......	55.5	......	....	559
	99	85.0	......	49.9	......	....	587
	100	74.5	......	42.6	......	....	572
	101	([a])	......	58.8	......	....	....
	102	108.9	......	69.3	......	....	636
Mean	......	......	......	......	......	....	596±12
Alfalfa, Peruvian, combined crop, June 7 to Oct. 23	97	167.1	......	108.7	......	....	650
	98	274.0	......	174.3	......	....	636
	99	242.4	......	152.7	......	....	630
	100	189.4	......	116.9	......	....	618
	102	299.1	......	216.2	......	....	723
Mean	......	......	......	......	......	....	651±12
Clover, red, S. P. I. 34869 (*Trifolium repens*), first crop, June 5 to July 19	103	99.7	......	73.1	......	....	733
	104	71.0	......	56.0	......	....	789
	105	89.6	......	60.3	......	....	673
	106	92.6	......	63.6	......	....	687
	107	116.3	......	82.0	......	....	705
	108	112.8	......	81.1	......	....	719
Mean	......	......	......	......	......	....	718±11

[a] Missing.

TABLE XX.—*Water requirement of legumes at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Clover, red, second crop, July 19 to Aug. 26	103	62.7		53.9			860
	104	66.0		53.0			803
	105	39.5		36.0			911
	106	62.8		53.9			858
	107	52.5		45.7			870
	108	46.6		44.4			953
Mean							876±14
Clover, red, third crop, Aug. 26 to Oct. 22	103	13.6		17.0			1,250
	104	18.3		17.4			952
	105	9.7		10.7			1,103
	106	8.5		9.0			1,058
	107	37.7		26.0			689
	108	10.4		12.9			1,040
Mean							1,015±49
Clover, red, combined crop, June 5 to Oct. 22	103	176.0		144.0			818
	104	155.3		126.4			814
	105	138.8		107.0			771
	106	163.9		126.5			772
	107	206.5		153.7			745
	108	169.8		138.4			815
Mean							789±9
Clover, crimson, S. P. I. 33742 (*Trifolium incarnatum*), June 5 to Aug. 26	109	191.3		160.8			841
	110	169.2		131.0			774
	111	186.2		150.5			809
	112	146.7		118.1			806
	113	109.8		84.9			773
	114	110.2		91.0			825
Mean							805±8
Vetch, hairy, S. P. I. 34298 (*Vicia villosa*), first crop, May 29 to July 18	181	119.4		93.3			781
	182	97.8		76.9			786
	183	98.1		95.9			977
	184	114.5		99.6			870
	185	121.9		98.9			811
	186	120.2		106.9			890
Mean							853±23
Vetch, hairy, second crop, July 18 to Oct. 22	181	114.8		61.7			537
	184	148.4		80.1			540
	185	155.7		92.6			595
	186	131.7		74.7			567
Mean							560±10
Vetch, hairy, combined crop, June 5 to Oct. 22	181	234.2		155.0			662
	184	262.9		179.7			684
	185	277.6		191.5			690
	186	251.9		181.6			722
Mean							690±8

TABLE XX.—*Water requirement of legumes at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Vetch, purple, S. P. I. 18131 (*Vicia atropurpurea*), May 29 to July 18	187	117.5		113.7			967
	188	118.5		108.8			919
	189	128.9		119.8			930
	190	113.8		106.0			932
	191	102.4		99.6			972
	192	115.2		102.3			888
Mean							935±9
Pea, Canada field, S. P. I. 30134 (*Pisum sativum*), June 3 to Aug. 4	241	154.0	64.7	117.9	42	1,822	766
	242	137.2	50.3	104.5	37	2,078	762
	243	136.3	46.6	103.8	34	2,228	762
	244	134.2	51.4	103.0	38	2,202	768
	245	120.0	32.8	96.0	27	2,921	800
	246	68.4	20.2	54.1	29	2,679	791
Mean						2,322±121	775±5
Bean, Mexican (*Phaseolus vulgaris*), May 28 to Sept. 1	229	282.4	120.8	213.9	43	1,769	757
	230	269.0	117.0	205.1	43	1,753	763
	231	260.7	108.9	191.0	42	1,755	733
	232	232.8	100.7	182.8	43	1,815	786
	233	276.2	111.9	218.4	40	1,952	791
	234	245.3	86.7	198.0	35	2,285	807
Mean						1,888±62	773±8
Bean, navy (*Phaseolus vulgaris*), May 28 to Aug. 21	223	220.3	101.2	144.6	46	1,429	656
	224	204.0	87.9	142.5	43	1,621	699
	225	224.5	95.6	153.3	43	1,604	683
	226	168.1	68.1	116.8	40	1,715	694
	227	227.9	90.5	153.3	40	1,693	673
	228	186.1	70.4	127.6	38	1,813	686
Mean						1,646±36	682±4
Bean, soy, S. P. I. 21755 (*Glycine hispida*), June 1 to Aug. 26	193	156.2	51.8	100.3	33	1,938	642
	194	144.7	51.9	91.4	36	1,760	631
	195	150.4	49.9	103.6	33	2,078	689
	196	158.2	48.5	110.3	31	2,275	698
	197	154.1	48.2	103.9	31	2,154	674
	198	160.0	52.9	111.7	33	2,110	698
Mean						2,053±51	672±9
Bean, soy, wild, S. P. I. 25138 (*Glycine soja*), June 12 to Sept. 14	199	255.9		238.8			934
	200	305.0		262.1			859
	201	346.1		260.6			754
	202	303.0		257.7			850
	203	374.9		262.8			701
	204	329.7		260.5			790
Mean							815±25

TABLE XX.—*Water requirement of legumes at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Cowpea, S. P. I. 29282 (*Vigna sinensis*), June 17 to Aug. 26...	151	207.0	69.9	123.1	34	1,761	595
	152	202.6	71.4	115.6	35	1,620	571
	153	215.7	80.1	121.7	37	1,519	564
	154	209.2	77.7	116.1	37	1,495	555
	155	210.6	75.0	120.0	36	1,600	570
	156	202.7	79.5	116.1	39	1,460	573
Mean..........	......	......	......	......	......	1,576±32	571±3
Bean, horse, S. P. I. 15429 (*Vicia faba*), June 12 to July 19...	169	38.3	......	31.0	......	....	809
	170	53.7	......	38.4	......	....	715
	171	44.6	......	33.4	......	....	749
	172	30.0	......	21.7	......	....	723
	173	10.0	......	8.7	......	....	870
	174	17.4	......	14.1	......	....	811
Mean..........	......	......	......	......	......	....	780±19
Bean, horse, S. P. I. 25645 (*Vicia faba*), June 17 to July 9...	175	9.4	......	7.1	......	....	755
	176	40.9	......	34.0	......	....	831
	177	29.4	......	21.8	......	....	742
	178	53.6	......	41.5	......	....	774
	179	18.5	......	13.5	......	....	730
	180	10.4	......	8.3	......	....	798
Mean..........	......	......	......	......	......	....	772±11

Neither variety of horse bean did well. The growth was fairly good during the early period, but during the warm days of July the plants wilted down badly, despite an ample water supply, and had to be harvested before they had reached maturity. The water requirement, notwithstanding this, is no higher than that of many of the other legumes, and compares favorably in this respect with hairy and with purple vetch. The navy bean, although not as efficient as the cowpea and the soy bean, is more efficient than the Mexican bean, which required 13 per cent more water. The Canada field pea and the Mexican bean were equally efficient.[1]

Crimson clover, on the basis of the combined crop, required practically the same quantity of water as red clover. Crimson clover produced only one crop and grew slowly throughout the period, although in total production it was practically the equal of red clover. The water requirement of red clover is slightly below that of Grimm alfalfa, while Peruvian alfalfa required only 78 per cent as much water as Grimm for the pro-

[1] Peas and beans were included by Lawes (1850, p. 54) in his experiments at Rothamstead, England. His measurements show beans to be slightly more efficient than peas. No other measurements of peas and beans have been made, so far as the writers are aware.

duction of a pound of dry matter. The total dry matter produced by Peruvian was, however, much less. The water requirement for each of the several cuttings made of these crops is shown in Table XXI.

TABLE XXI.—*Water requirement of different cuttings of legumes*

Crop.	First cutting.	Second cutting.	Third cutting.	Combined cutting.
Alfalfa, Peruvian	651±16	725±18	596±12	651±12
Clover, red	718±11	876±14	1,015±49	789±9
Alfalfa, Grimm	804±9	878±8	818±11	834±8
Vetch, hairy	853±23	560±10	....	690±8

Taking the water requirement of the first cutting in each instance as a basis of comparison, the second crop of Grimm alfalfa required 8 per cent more water, Peruvian alfalfa 11 per cent more, red clover 22 per cent more, while hairy vetch required 34 per cent less. On the same basis the third cutting of Grimm alfalfa required 2 per cent more water than the first, 8 per cent more for Peruvian, and red clover 41 per cent more. Comparing the combined cuttings, Peruvian alfalfa and hairy vetch required 18 per cent less water than Grimm, and red clover 5 per cent less. Grimm alfalfa was the only one of the lupines grown at Akron during both 1912 and 1913. Its water requirement in 1912 was 659±16; in 1913, 834±8, an increase of 27 per cent.

ALFALFA, SUDAN GRASS, AND MILLET GROWN DURING THE LATE SUMMER AND AUTUMN AT AKRON, COLO., IN 1912

In Table XXII are given the results of water-requirement measurements based on the total dry matter produced by crops grown during the late summer and autumn and planted in pots which had already produced a crop earlier in the season. The soil was not changed, and no additional fertilizer was added. These forage crops can not be said to have been grown out of season, except in that the plantings were made too late in the season to permit the plants to reach their full development before harvesting.

TABLE XXII.—*Water requirement of alfalfa, Sudan grass, and millet grown during the late summer and autumn at Akron, Colo., in 1912, without additional fertilizer.*

Crop.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1912.		*Grams.*	*Kilos.*	
Alfalfa, Grimm, E-23-20-52 (*Medicago sativa*), Aug. 7 to Nov. 6, following Kharkov wheat	37	40.9	40.4	988
	39	43.1	37.3	866
	40	33.2	31.7	955
	41	32.0	30.2	944
	42	34.3	34.9	1,017
Mean	.....	....	....	954±16

TABLE XXII.—*Water requirement of alfalfa, Sudan grass, and millet grown during the late summer and autumn at Akron, Colo., in 1912, without additional fertilizer*—Continued

Crop.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*	
Alfalfa, Grimm, following Turkey wheat	43	40.4	34.8	862
	44	45.3	40.5	894
	45	21.0	21.3	1,013
	46	25.6	23.0	899
	47	30.7	26.9	876
	48	33.0	30.7	930
Mean				912±15
Alfalfa, Grimm, Sept. 3 to Nov. 7, following Bluestem wheat	31	14.7	7.5	510
	32	16.8	8.5	506
	33	18.1	8.3	458
	34	19.6	8.1	413
	35	13.8	6.1	442
	36	12.9	6.6	511
Mean				473±13
Alfalfa, Grimm, following unfertilized Kubanka wheat	7	14.7	9.3	628
	8	19.8	10.8	545
	9	15.0	9.1	606
	10	16.4	9.5	579
	12	16.7	9.5	569
Mean				585±11
Alfalfa, Grimm, Sept. 9 to Nov. 4, following *Grindelia squarrosa*	163	12.9	7.5	581
	164	11.8	6.4	542
Mean				564±16
Alfalfa, yellow flowered (*Medicago falcata*), Sept. 3 to Nov. 7, following Kubanka wheat	4	10.0	4.6	460
	5	10.8	5.1	472
	6	16.5	8.3	503
Mean				478±10
Sudan grass, S. P. I. 25017 (*Andropogon sorghum aethiopicus*), Sept. 3 to Oct. 1, following spring Ghirka wheat	55	11.5	3.0	261
	56	18.1	5.4	298
	57	10.5	3.1	295
	58	19.5	5.8	297
	59	16.6	5.7	343
	60	9.6	3.4	354
Mean				308±10
Proso, Black Voronezh, S. D. 331 (*Panicum miliaceum*), Aug. 22 to Sept. 28, following Beldi barley	97	20.0	4.4	220
	98	25.0	5.8	232
	99	19.5	3.7	190
	101	15.5	4.0	258
	102	20.0	4.6	230
Mean				226±7

TABLE XXII.—*Water requirement of alfalfa, Sudan grass, and millet grown during the late summer and autumn at Akron, Colo., in 1912, without additional fertilizer*—Continued

Crop.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*	
Millet, Turkestan, S. P. I. 20694 (*Chaetochloa italica*), Aug. 22 to Oct. 1, following White Hull-less barley	103	27.0	7.8	289
	104	28.3	8.5	300
	105	30.7	8.4	273
	106	30.4	8.9	293
	107	33.5	9.2	274
	108	35.1	11.7	333
Mean				294±6
Millet, Kursk, S. P. I. 30029 (*Chaetochloa italica*), Sept. 3 to Oct. 3, following spring rye	115	9.3	1.8	194
	116	12.4	2.5	202
	117	19.3	4.0	207
	118	24.2	3.9	161
	119	23.5	3.1	132
	120	12.3	1.8	146
Mean				173±10
Millet, Kursk, S. P. I. 34771, Sept. 3 to Oct. 1, following emmer	61	22.2	3.7	167
	62	18.4	2.9	158
	63	23.4	3.7	158
	64	21.6	3.8	176
	65	24.7	3.7	150
	66	24.5	3.8	155
Mean				161±3

The effect of fertilizer added to the previous crop on the water requirement of the next crop is shown in the following measurements:

Crop	Water requirement
Alfalfa, following fertilized Bluestem wheat	473±13
Alfalfa, following unfertilized Kubanka wheat	585±11
Alfalfa, following fertilized Grindelia, following unfertilized Bluestem wheat	564±16

The water requirement of alfalfa following unfertilized Kubanka wheat was higher than that following the fertilized Bluestem, and although this difference is not very marked (19±3 per cent) when the probable error is considered, it is sufficient to show a slight effect of two consecutive crops without fertilizer in increasing the water requirement. Two pots of alfalfa following *Grindelia squarrosa* had a water requirement equal to that of the unfertilized set. Grindelia was started in pots which had already produced a crop of Marvel Bluestem wheat in 1911 without fertilizer. Therefore alfalfa was the third crop from the same soil mass, and although the pots growing Grindelia were fertilized, the succeeding alfalfa crop gave a water requirement in accord with that following unfertilized wheat.

The effect of time of planting is shown in the following determinations of the water requirement of alfalfa:

Crop	Water requirement
Alfalfa, grown August 7 to November 6, following Kharkov wheat	954 ± 16
Alfalfa, grown August 7 to November 6, following Turkey wheat.	912 ± 15
Alfalfa, grown September 3 to November 7, following Bluestem wheat	473 ± 13

Alfalfa planted during the dry, hot days of August required almost twice as much water for the production of a unit of dry matter as it did when planted in September.

The seven varieties and strains given in Table XXIII were included in these late-season experiments and were grown under comparable conditions. The water requirement of Grimm alfalfa, Sudan grass, and Kursk millet was also determined in midsummer (see column 3), so that it is possible to reduce the water-requirement measurement of the other late-season crops to a midsummer basis. The seasonal water requirement of Grimm alfalfa was 39 per cent higher than that of the late-season crop. Assuming this ratio to hold for the yellow-flowered alfalfa, the seasonal water requirement of the latter would be 865 ± 18. The midsummer water requirement of Sudan grass and of Kursk millet (S. P. I. 34771) was in each instance 16 per cent above the late-season crop, and this ratio has been used in computing the other millets to a midsummer basis. The computed values (a) are given in the last column of Table XXIII.

Table XXIII.—*Water requirement of late-season crops*

Variety.	Water requirement.	
	Late-season crop.	Midsummer crop.
Alfalfa, yellow-flowered	478 ± 10	[a] 865 ± 18
Alfalfa, Grimm	473 ± 13	657 ± 11
Sudan grass	308 ± 10	359 ± 2
Millet, Turkestan	294 ± 6	[a] 341 ± 7
Proso, Black Voronezh	226 ± 7	[a] 262 ± 8
Millet, Kursk, S. P. I. 30029	173 ± 10	[a] 201 ± 12
Millet, Kursk, S. P. I. 34771	161 ± 3	187 ± 2

[a] Computed.

Of these seven varieties the yellow-flowered alfalfa (*Medicago falcata*) gave a water requirement in practical accord with the Grimm selection grown during the same period. Kursk millet (S. P. I. 34771) gave the lowest water requirement and proved to be decidedly more efficient than Black Voronezh proso and Turkestan millet. Sudan grass required 91 per cent more water than the Kursk millet, which is in exact accord with the results obtained for these two crops from determinations based on a whole season's growth.

CUCURBITS

On account of the large space required by crops which produce vines, the cucurbits were grown outside the inclosure at Akron in 1913. The reduction in water requirement produced by the inclosure amounted in the case of wheat, alfalfa, and cocklebur to approximately 20 per cent. These ratios for the cucurbits should therefore be reduced by this amount in comparing them with crops grown inside the shelter. The observed water requirement outside and the computed water requirement within the inclosure, both based on dry matter, follow:

Crop	Outside	Inside
Watermelon	750±19	600±15
Cantaloupe	778±34	621±27
Cucumber	891±14	713±11
Squash	936±10	748±8
Pumpkin	1,043±21	834±17

The cucumber, cantaloupe (Pl. VI, fig. 4), and watermelon did well in the pots. Squash and pumpkin produced very little fruit (Table XXIV), and the growth of vines was not normal. Watermelon and muskmelon proved to be the most efficient of the cucurbits. Pumpkin, the highest of the cucurbits in water requirement, is about the equal of alfalfa in efficiency.

TABLE XXIV.—*Water requirement of cucurbits at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Dry matter in fruit.	Water.	Fruit.	Water requirement based on— Fruit.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Squash, Hubbard (*Cucurbita maxima*), June 3 to Sept. 13	337	272.0	46.1	260.7	17	5,658	959
	338	280.9	85.6	252.1	30	2,945	898
	339	244.3	33.4	224.2	14	6,715	918
	340	247.3	18.4	242.9	7	......	982
	341	267.9	68.6	244.9	26	3,570	914
	342	258.9	7.3	244.7	3	......	946
Mean						4,720±690	936±10
Pumpkin, common field (*Cucurbita pepo*), June 3 to Sept. 13	343	205.9	......	215.6	......	......	1,047
	344	222.4	5.9	221.0	3	......	994
	345	228.8	45.9	211.6	20	......	925
	346	225.4	2.8	243.2	1	......	1,078
	347	190.5	......	215.2	......	......	1,130
	348	179.7	2.8	194.6	2	......	1,083
Mean						......	1,043±21
Cucumber, Boston pickling (*Cucumis sativus*), June 14 to Sept. 1	319	171.1	101.5	154.8	59	1,525	905
	320	185.6	100.0	167.6	54	1,676	903
	321	185.7	96.3	158.2	42	1,642	852
	322	182.5	112.4	152.9	62	1,360	838
	323	175.8	83.7	171.1	48	2,045	974
	324	174.8	107.4	152.3	61	1,417	872
Mean						1,611±67	891±14

TABLE XXIV.—*Water requirement of cucurbits at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Dry matter in fruit.	Water.	Fruit.	Water requirement based on—	
						Fruit.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Cantaloupe, Rocky Ford (*Cucumis melo*), June 14 to Sept. 13	325	314.7	198.9	201.7	63	1,014	641
	326	285.3	155.2	214.4	55	1,382	752
	327	211.4	92.5	210.5	44	2,276	996
	328	264.9	132.5	218.1	50	1,646	824
	329	272.8	160.6	197.3	59	1,228	723
	330	305.6	162.4	222.8	53	1,371	729
Mean						1,486±120	778±34
Watermelon, Rocky Ford (*Citrullus vulgaris*), June 14 to Sept. 13	331	301.8	193.2	238.2	64	1,233	790
	332	318.5	216.8	215.5	68	995	677
	333	334.5	225.9	241.4	67	1,069	722
	334	314.2	209.1	232.8	66	1,112	740
	335	267.9	159.4	232.1	59	1,457	866
	336	320.8	224.2	226.5	70	1,010	706
Mean						1,146±49	750±19

On the basis of the production of fruit the watermelon has proven to be exceptionally efficient. The water requirement, calculated on the basis of the dry matter in the melons and reduced to inclosure conditions, was 915±39. The green fruit contained 95 per cent of water. The water requirement on a green basis would therefore be 46.

RAPE, TURNIP, CABBAGE, AND POTATO

Rape, turnip, cabbage, and two varieties of potato, the Irish Cobbler and the McCormick (Pl. VI, fig. 6), were included in the 1913 measurements (Table XXV). The water requirement, based on dry matter, was as follows:

Crop	Water requirement
Cabbage	539±7
Turnip	639±31
Potato:	
Irish Cobbler	659±15
McCormick	717±11
Rape	743±7

Cabbage and turnip are seen to have a lower water requirement than potato and to rank in efficiency with oats. Of the potato varieties the Irish Cobbler was the more efficient and produced the most tubers. The McCormick, a late-maturing variety, produced fine vines but practically no tubers. The water requirement of rape was practically the same as that of turnip during the same period of growth, but the second crop, although not a heavy one, had a water requirement so much higher than the first that the combined crop is approximately 16 per cent higher than for turnip.

TABLE XXV.—*Water requirement of rape, turnip, cabbage, and potato at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Tubers or roots.	Water.	Tubers or roots.	Water requirement based on—	
						Tubers or roots.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Rape (*Brassica napus*), June 3 to July 19....	217	171.2	......	112.1	......	....	655
	218	156.3	......	102.9	......	....	658
	219	162.0	......	102.5	......	....	633
	220	140.5	......	97.4	......	....	693
	221	171.5	......	108.0	......	....	630
	222	164.6	......	110.5	......	....	671
Mean..........	......	......	......	......	......	....	657±6
Rape, second crop, July 19 to Sept. 13..	217	44.6	......	54.3	......	....	1,217
	218	68.5	......	69.2	......	....	1,010
	219	58.3	......	58.0	......	....	995
	220	63.8	......	53.2	......	....	834
	221	66.4	......	62.8	......	....	946
	222	69.0	......	60.9	......	....	882
Mean..........	......	......	......	......	......	....	981±35
Rape, combined crop, June 3 to Sept. 13...	217	215.8	......	166.4	......	....	771
	218	224.8	......	172.1	......	....	767
	219	220.3	......	160.5	......	....	729
	220	204.3	......	150.6	......	....	737
	221	237.9	......	170.8	......	....	718
	222	233.6	......	171.4	......	....	734
Mean..........	......	......	......	......	......	....	743±7
Turnip, Purple Top (*Brassica rapa*), May 29 to July 19........	211	128.9	69.3	78.1	54	1,127	606
	212	128.4	64.6	90.7	50	1,403	706
	213	58.6	17.3	30.6	29	1,767	522
	214	128.5	58.8	69.5	45	1,181	541
	215	73.8	37.6	51.2	51	1,360	694
	216	90.4	29.4	68.9	32	2,341	762
Mean..........	......	......	......	......	......	1,530±132	639±31
Cabbage, Early Jersey Wakefield (*Brassica oleracea capitata*), June 3 to Sept. 12...	205	284.5	......	148.9	......	....	523
	206	281.9	......	160.3	......	....	569
	207	359.8	......	191.5	......	....	533
	208	330.7	......	176.0	......	....	532
	209	344.6	......	175.7	......	....	510
	210	313.2	......	177.0	......	....	565
Mean..........	......	......	......	......	......	....	539±7
Potato, Irish Cobbler (*Solanum tuberosum*), June 5 to Sept. 12............	115	170.2	40.6	120.4	24	2,966	708
	116	203.2	67.8	145.1	33	2,140	714
	117	211.0	81.7	127.0	39	1,555	602
	118	222.3	86.6	149.3	39	1,724	671
	119	218.1	105.3	130.0	48	1,234	596
	120	201.1	52.4	133.3	26	2,542	662
Mean..........	......	......	......	......	......	2,027±197	659±15
Potato, McCormick (*Solanum tuberosum*), June 5 to Oct. 4..............	121	215.8	.1	145.5	......	....	674
	122	213.7	1.7	154.9	......	....	724
	123	215.5	5.0	146.9	2	....	682
	124	219.3	10.3	164.5	5	....	750
	125	201.4	.3	154.2	......	....	766
	126	206.9	1.9	145.9	1	....	706
Mean..........	......	......	......	......	......	....	717±11

NATIVE AND INTRODUCED GRASSES AND OTHER NATIVE PLANTS

Two native Colorado plants were included in the 1912 measurements at Akron, *Grindelia squarrosa*, or "gum weed," and *Artemisia frigida*, or "mountain sage" (Pl. II, fig. 3). These plants were carried through the winter in the pots, and only two pots of each set were in good condition in the spring. They both behaved as biennials, forming rosettes in 1911 and flowering profusely in 1912. The data (Table XXVI) given for the period from May 20 to August 26 include much of the stored dry matter of the rosettes and root systems elaborated during an earlier period, and consequently the water requirement is somewhat too low. In order to check this, the data based on the total period of growth, which includes the growth and water consumption in 1911, have also been given. This method of computation increases the water requirement less than 6 per cent.

TABLE XXVI.—*Water requirement of native plants at Akron, Colo., in 1912*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1912.		*Grams.*	*Kilos.*	
Grindelia squarrosa, May 20 to Aug. 26	163	385.4	172.0	446
	164	367.7	180.0	490
Mean				468±18
Artemisia frigida, May 20 to Aug. 26	167	336.3	153.4	456
	168	293.9	143.9	491
Mean				474±14
TOTAL PERIOD OF GROWTH.				
Grindelia squarrosa, Aug. 18, 1911, to Aug. 26, 1912	163	399.6	182.4	457
	164	381.2	200.5	526
Mean				492±29
Artemisia frigida, Jan. 10, 1911, to Aug. 26, 1912	167	372.8	177.4	476
	168	345.8	183.9	532
Mean				504±24

Although these are typical native plants of the high plains, they required about 20 per cent more water than Kubanka wheat and rank higher in water consumption than any of the cultivated grains except rye and rice.

Grasses produce so slowly that it is somewhat difficult to make satisfactory measurements of their water requirement. The 1913 experiments (Table XXVII) included pure buffalo grass, mixed grama and

buffalo grass, western wheat-grass, brome-grass, and a Siberian wheat-grass. Buffalo grass, brome-grass, and wheat-grass each gave two crops, buffalo and grama mixed gave three cuttings, while western wheat-grass produced but one cutting. The combined crops afford the best basis for the comparison of these grasses. On the basis of the total dry matter produced throughout the season, the water requirement is as follows:

Variety of grass	Water requirement
Buffalo	308±22
Grama and buffalo	389±12
Wheat-grass	705±27
Brome-grass	1,016±26
Western wheat-grass	1,076±29

Brome-grass and western wheat-grass are comparatively very inefficient in the use of water, requiring from 22 to 29 per cent more water than alfalfa. Western wheat-grass made a slow growth. Wheat-grass is more efficient than alfalfa, requiring 15 per cent less water. The short grasses made a wonderful showing, the water requirement of pure buffalo grass being only about one-third that of alfalfa, and that of grama and buffalo mixed, 47 per cent. The water requirement of buffalo grass is only 8 per cent above millet, which is one of the most efficient of the introduced plants. The mixed buffalo and grama grass required 36 per cent more water than Kursk millet. These are the first of the native plants to show any marked efficiency in the use of water, although some of the weeds, as will be seen later, are also highly efficient.

TABLE XXVII.—*Water requirement of native and introduced grasses at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1913.		*Grams.*	*Kilos.*	
Grama (*Bouteloua gracilis*) and buffalo grass (*Bulbilis dactyloides*), mixed, first crop, June 3 to July 19	139	50.1	17.4	347
	140	26.9	10.7	398
	141	31.8	12.4	390
	142	21.9	7.5	342
	143	22.1	9.8	443
	144	25.3	8.6	340
Mean				377±11
Grama and buffalo grass, mixed, second crop, July 19 to Aug. 26	139	51.7	18.1	350
	140	35.4	13.2	373
	141	38.8	15.6	402
	142	37.9	14.4	380
	143	41.2	16.1	391
	144	26.1	9.7	371
Mean				395± 7

TABLE XXVII.—*Water requirement of native and introduced grasses at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1913.		*Grams.*	*Kilos.*	
Grama and buffalo grass, mixed, third crop, Aug. 26 to Oct. 20	139	14.3	7.4	517
	140	11.6	6.1	526
	141	11.8	7.0	593
	142	15.9	7.1	446
	143	15.0	7.6	507
	144	18.3	4.3	235
Mean				471±26
Grama and buffalo grass, mixed, combined crops, June 3 to Oct. 20	139	116.1	42.9	369
	140	73.9	30.0	406
	141	82.4	35.0	425
	142	75.7	29.0	383
	143	78.3	33.5	428
	144	69.7	22.6	324
Mean				389±12
Buffalo grass (*Bulbilis, dactyloides*), first crop, June 18 to Aug. 26	145	10.0	3.5	350
	146	32.1	9.0	280
	147	18.9	5.0	264
	148	12.9	3.8	295
	149	13.2	3.8	288
	150	8.1	1.5	185
Mean				277±13
Buffalo grass, second crop, Aug. 26 to Oct. 18	145	3.6	1.5	417
	146	3.1	.8	258
	147	2.3	.7	304
	148	5.2	1.9	365
Mean				336±23
Buffalo-grass, combined crops, June 18 to Oct. 18	145	13.6	5.0	368
	146	35.2	9.8	278
	147	21.2	5.7	269
	148	18.1	5.7	315
Mean				308±17
Brome-grass, S. P. I. 29880 (*Bromus inermis*), first crop, May 23 to July 19	133	64.5	62.8	973
	134	75.2	74.6	992
	135	76.0	70.3	925
	136	60.8	58.6	964
	138	79.5	79.3	998
Mean				970±9
Brome-grass, second crop, July 19 to Oct. 22	133	30.3	28.4	937
	134	46.1	59.3	1,286
	135	36.1	46.6	1,290
	136	26.9	21.8	810
	138	40.1	47.0	1,172
Mean				1,099±76

TABLE XXVII.—*Water requirement of native and introduced grasses at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
1913.		*Grams.*	*Kilos.*	
Brome-grass, combined crops, May 23 to Oct. 22.	133	94.8	91.2	962
	134	121.3	133.9	1,104
	135	112.1	116.9	1,043
	136	87.7	80.4	916
	138	119.6	126.3	1,056
Mean				1,016±26
Wheat-grass (*Agropyron cristatum*), S. P. I. 19537, first crop, June 5 to July 19	67	25.9	19.2	741
	68	33.6	22.4	667
	69	24.3	16.1	663
	70	23.0	19.3	839
	71	17.1	13.8	808
	72	34.0	25.8	759
Mean				746±21
Wheat-grass, second crop, July 19 to Oct. 22	67	49.0	37.9	773
	68	77.0	45.1	585
	69	53.6	29.3	547
	70	58.0	40.2	693
	71	46.1	34.8	755
	72	66.2	51.3	775
Mean				688±31
Wheat-grass, combined crop, June 5 to Oct. 22	67	74.9	57.1	762
	68	110.6	67.5	610
	69	77.9	45.4	583
	70	81.0	59.5	735
	71	63.2	48.6	769
	72	100.2	77.1	769
Mean				705±27
Wheat-grass, western (*Agropyron Smithii*), June 17 to Oct. 22	235	37.7	45.0	1,193
	236	41.4	43.1	1,040
	237	18.3	15.2	831
	238	21.1	23.0	1,087
	239	25.6	28.9	1,128
	240	16.7	19.7	1,179
Mean				1,076±29

WEEDS

A number of weeds were grown in pots at Akron in 1913, in order to determine their water requirement. (Table XXVIII.) Most of these were planted late in the season, after the crops of grain had been removed. Pigweed and the annual sunflower were, however, started at the beginning of the season. Three crops of pigweed were produced, the water requirement for the first, second, third, and combined cuttings, based on dry matter, being 325±10, 326±4, 278±7, and 320±7, respectively.

Sunflower, which made an excellent growth, gave a water requirement of 705±8. Sunflower thus requires almost three times as much water as pigweed and 86 per cent as much water as alfalfa.

A comparison of the water requirement of pigweed during the three periods of growth will show that the water requirement is not greatly affected by the period of growth.

If this holds for the other weeds, no great error will be produced in comparing the water requirement of these plants without regard to the period during which they were grown. The water requirement is, however, probably slightly less than it would have been if the plants had been grown in midsummer. The results obtained, based on the production of dry matter, are as follows:

Variety of weed	Water requirement
Purslane (*Portulaca oleracea*)	292±11
Pigweed (*Amaranthus retroflexus*)	320±7
Cocklebur (*Xanthium commune*)	432±13
Narrow-leaved sunflower from sand hills (*Helianthus petiolaris*)	570±11
Annual sunflower (*Helianthus annuus*)	705±8
Narrow-leaved sunflower from near Akron (*Helianthus petiolaris*)	774±20
Lamb's-quarters (*Chenopodium album*)	801±41
Fetid marigold (*Boebera papposa*)	881±26
Western ragweed (*Ambrosia artemisifolia*)	948±66

Purslane and pigweed, two introduced weeds, appear to be exceptionally efficient plants, their water requirement being only slightly higher than that of Kursk millet and in practical agreement with the sorghums. Some of the indigenous weeds were also found to be fairly efficient, cocklebur, a plant found in stream beds and about ponds, having a water requirement 13 per cent less than wheat, while the narrow-leaved sunflower from the sand hills had a water requirement 31 per cent less than alfalfa. Lamb's-quarters, an introduced plant, and fetid marigold (Pl. VII, fig. 2) and western ragweed, indigenous plants, have a slightly higher water requirement than alfalfa.

It is evident, therefore, that the common weeds differ greatly in water requirement. A growth of weeds in a crop or on summer fallow represents a tremendous loss of moisture, a thousand pounds per acre of the most efficient weeds representing a loss of at least 1.5 inches of stored rainfall, or from 4 to 5 inches of stored rainfall in the case of the weeds having a high water requirement. The latter figures represent about the maximum amount of moisture that can be stored in fallow land. It is therefore easy to understand how the whole of the stored moisture supply may be lost through the growth of a moderate crop of weeds, and these varieties having a high water requirement are especially to be dreaded.

TABLE XXVIII.—*Water requirement of weeds at Akron, Colo., in 1913*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Sunflower (*Helianthus annuus*), June 5 to Sept. 15	271	516.6	40.7	373.5	8	9,180	723
	272	554.0	70.5	363.9	13	5,161	657
	273	502.2	51.8	343.2	10	6,625	683
	274	459.2	58.4	334.9	13	5,725	729
	275	512.5	63.0	371.6	12	5,900	724
	276	507.2	63.2	360.9	12	5,710	711
Mean						6,384±383	705±8
Sunflower, narrow-leaved (*Helianthus petiolaris*), July 25 to Sept. 17	175	196.0	34.1	135.5	17	3,971	691
	176	140.4	19.6	103.1	21	5,261	735
	177	148.7	23.3	109.5	16	4,695	736
	178	103.4	16.7	87.1	16	5,218	842
	179	156.0	21.8	132.2	14	6,061	848
	180	163.7	25.2	129.6	15	5,141	792
Mean						5,058±132	774±20
Sunflower, narrow-leaved (*Helianthus petiolaris*), from Sand hills, Aug. 13 to Sept. 18	79	17.1		10.0			585
	80	32.3		18.6			576
	81	34.6		18.2			526
	82	14.4		9.1			632
	83	25.4		13.5			531
	84	30.5		17.3			567
Mean							570±11
Marigold, fetid (*Boebera papposa*), July 25 to Sept. 17	169	116.0		95.8			826
	170	102.8		98.8			960
	171	106.5		93.3			876
	172	99.9		86.7			868
	173	167.3		125.5			750
	174	55.0		55.2			1,004
Mean							881±26
Lamb's-quarters (*Chenopodium album*), July 25 to Sept. 17	211	64.0		39.9			624
	212	35.3		26.9			762
	213	47.4		46.2			975
	214	40.0		33.4			835
	215	51.6		47.2			914
	216	64.2		44.6			694
Mean							801±41
Ragweed, western (*Ambrosia artemisifolia*), Aug. 1 to Sept. 18	187	17.1		12.5			731
	188	12.3		12.9			1,049
	189	10.6		13.8			1,302
	190	20.6		18.7			908
	191	13.1		13.3			1,015
	192	27.5		18.7			680
Mean							948±66

TABLE XXVIII.—*Water requirement of weeds at Akron, Colo., in 1913*—Continued

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Dry matter.
1913.		*Grams.*	*Grams.*	*Kilos.*	*Per cent.*		
Pigweed (*Amaranthus retroflexus*), June 12 to July 19	91	56.9	......	18.8	......	....	330
	92	133.7	......	50.2	......	....	377
	93	145.7	......	44.6	......	....	306
	94	115.0	......	33.7	......	....	293
	95	112.8	......	33.5	......	....	297
	96	161.5	......	55.7	......	....	345
Mean	......	......	......	......	......	....	325±10
Pigweed, second crop, July 19 to Sept. 1	91	74.9	......	22.5	......	....	300
	92	62.2	......	20.1	......	....	323
	93	50.0	......	16.4	......	....	328
	94	54.9	......	17.9	......	....	326
	95	60.9	......	20.5	......	....	337
	96	50.6	......	17.2	......	....	340
Mean	......	......	......	......	......	....	326±4
Pigweed, third crop, Sept. 1 to Oct. 4	91	7.5	......	2.2	......	....	293
	92	11.6	......	3.6	......	....	310
	93	11.8	......	3.4	......	....	288
	94	16.7	......	4.2	......	....	251
	95	14.9	......	3.9	......	....	262
	96	18.6	......	4.9	......	....	263
Mean	......	......	......	......	......	....	278±7
Pigweed, combined crops, June 12 to Oct. 4	91	139.3	......	43.5	......	....	312
	92	207.5	......	73.9	......	....	356
	93	207.5	......	64.4	......	....	310
	94	186.6	......	55.8	......	....	299
	95	188.6	......	57.9	......	....	307
	96	230.7	......	77.8	......	....	337
Mean	......	......	......	......	......	....	320±7
Purslane (*Portulaca oleracea*), July 18 to Sept. 17	183	103.1	......	33.2	......	....	322
Purslane, Aug. 21 to Sept. 17	241	36.2	......	8.9	......	....	246
	242	28.0	......	7.5	......	....	268
	243	33.5	......	9.7	......	....	289
	244	38.4	......	10.9	......	....	284
	245	48.5	......	12.9	......	....	266
	246	18.8	......	7.0	......	....	372
Mean	......	......	......	......	......	....	292±11

RELATIVE WATER-REQUIREMENT MEASUREMENTS

The relative water requirement of the different varieties of plants grown at Akron in 1912 is summarized in Table XXIX, Kubanka wheat being used as a basis of comparison. Grimm alfalfa is seen to have the highest water requirement of the 42 species and varieties tested during 1912, while Kursk millet proved the most efficient of all the plants tested. The varieties are also grouped on the basis of crop or genus, and their mean water requirement compared with the mean water require-

ment of the wheat varieties. The relative water requirement on this basis is given in the last column of Table XXIX.

The quantity of water required by the various crops for the production of a unit amount of seed or grain at Akron in 1912 is summarized in Table XXIV. Rye is seen to be the least efficient of the grain-producing crops tested, with Voronezh proso the most efficient.

TABLE XXIX.—*Summary of water-requirement measurements at Akron, Colo., in 1912*

WATER REQUIREMENT BASED ON DRY MATTER PRODUCED

Crop and variety.	Botanical name.	Water requirement of— Variety. Actual.	Variety. Relative, compared with Kubanka wheat.	Crop (or genus). Actual.	Crop (or genus). Relative, compared with wheat (*Triticum* spp.).
1912.					
Alfalfa:					
Grimm, S. P. I. 25695.	Medicago sativa	659±6	1.67±0.03	658	1.60
Grimm, A. D. I. E. 23-20-52.	do	657±11	1.67± .04		
Clover, sweet	Melilotus alba	638±4	1.62± .03	638	1.56
Rice, Honduras	Oryza sativa	519±13	1.32± .04	519	1.27
Chick-pea	Cicer arietinum	510±14	1.29± .04	510	1.24
Rye, spring	Secale cereale	496±9	1.26± .03	496	1.21
Cotton, Triumph	Gossypium hirsutum.	488±14	1.24± .04	488	1.19
Native plants	Artemisia frigida	474±14	1.20± .04	471	1.15
	Grindelia squarrosa.	468±18	1.19± .05		
Oats:					
Sixty-Day	Avena sativa	491±13	1.25± .04	441	1.08
Burt	do	449±3	1.14± .02		
Swedish Select	do	423±5	1.07± .02		
Canadian	do	399±6	1.01± .02		
Barley:					
Hannchen	Hordeum distichon.	443±3	1.12± .02	425	1.04
White Hull-less	Hordeum vulgare	439±1	1.11± .02		
Beldi	do	416±4	1.06± .02		
Beardless	do	403±8	1.02± .03		
Wheat:					
Spring Ghirka	Triticum aestivum	457±3	1.16± .02	410	1.00
Marvel Bluestem	do	451±4	1.14± .02		
Emmer	Triticum dicoccum	428±3	1.09± .02		
Kubanka	Triticum durum	394±7	1.00		
Kharkov	Triticum aestivum	365±6	.93± .02		
Turkey	do	364±6	.92± .02		
Sugar beet:					
Kleinwanzleben	Beta vulgaris	321±8	.81± .03	321	.78
Corn:					
China White	Zea mays	315±7	.80± .02	286	.70
Iowa Silvermine	do	302±7	.77± .02		
Laguna	do	295±6	.75± .02		
China White×Laguna.	do	289±4	.73± .02		
Hopi	do	285±7	.72± .02		
Northwestern Dent.	do	280±10	.71± .03		
China White×Esperanza.	do	250±2	.63± .01		
Esperanza	do	239±3	.61± .01		

TABLE XXIX.—*Summary of water-requirement measurements at Akron, Colo., in 1912*—Continued

WATER REQUIREMENT BASED ON DRY MATTER PRODUCED—Continued

Crop and variety.	Botanical name.	Water requirement of— Variety. Actual.	Water requirement of— Variety. Relative, compared with Kubanka wheat.	Water requirement of— Crop (or genus). Actual.	Water requirement of— Crop (or genus). Relative, compared with wheat (*Triticum* spp.).
1912.					
Sorghum:					
Sudan grass	Andropogon sorghum aethiopicus.	359±2	0.91±0.02		
Milo, Dwarf	Andropogon sorghum	273±4	.69± .02		
Kafir, Blackhull	do	259±5	.66± .02		
Durra, White	do	255±3	.65± .02	262	0.64
Milo	do	249±3	.63± .02		
Minnesota Amber	do	239±2	.61± .01		
Red Amber	do	237±4	.60± .01		
Kaoliang, Brown	do	223±1	.57± .01		
Millet:					
German	Chaetochloa italica	248±7	.63± .02	218	.53
Kursk	do	187±2	.47± .01	207	.51
Proso:					
Tambov	Panicum miliaceum	208±1	.53± .01	207	.51
Voronezh	do	206±1	.52± .01		

WATER REQUIREMENT BASED ON GRAIN OR SEED PRODUCED

Crop and variety.	Botanical name.	Variety. Actual.	Variety. Relative, compared with Kubanka wheat.	Crop (or genus). Actual.	Crop (or genus). Relative, compared with wheat (*Triticum* spp.).
Rye, spring	Secale cereale	1,802±62	1.61±0.08	1,802	1.50
Chick-pea	Cicer arietinum	1,348±114	1.21± .11	1,348	1.13
Oats:					
Canadian	Avena sativa	1,416±119	1.27± .12		
Burt	do	1,224±55	1.10± .07	1,229	1.03
Sixty-Day	do	1,172±133	1.05± .12		
Swedish Select	do	1,103±18	.99± .04		
Wheat:					
Marvel Bluestem	Triticum aestivum	1,573±49	1.42± .06		
Spring Ghirka	do	1,468±34	1.32± .06		
Kubanka	Triticum durum	1,111±37	1.00	1,197	1.00
Kharkov	Triticum aestivum	1,064±60	.96± .06		
Turkey	do	995±22	.90± .04		
Emmer	Triticum dicoccum	984±18	.89± .03		
Barley:					
White Hull-less	Hordeum vulgare	1,239±11	1.11± .04		
Beardless	do	1,017±83	.92± .08	1,051	.88
Hannchen	Hordeum distichon	1,005±36	.90± .04		
Beldi	Hordeum vulgare	941±10	.84± .03		
Sorghum:					
Kaoliang, Brown	Andropogon sorghum.	927±38	.83± .04	767	.64
Minnesota Amber	do	607±15	.55± .02		
Millet:					
Kursk	Chaetochloa italica	483±11	.43± .02	483	.41
Proso:					
Tambov	Panicum miliaceum	482±9	.43± .02	454	.38
Voronezh	do	425±4	.38± .01		

The relative water requirement of the different varieties included in the 1913 experiments will be found summarized on the basis of dry matter in Table XXX and on the basis of grain production in Table XXXI. Fifty-five species and varieties were included in these measurements. Reference to these tables will show that a number of plants had a higher water requirement than alfalfa, heretofore the most inefficient in the use of water of any plant included in these experiments. On the other hand, millet maintains its supremacy as the most efficient plant so far included in the water-requirement measurements.

TABLE XXX.—*Summary of water-requirement measurements at Akron, Colo., in 1913, based on dry matter produced*

Crop and variety.	Botanical name.	Water requirement.	Relative, as compared with Kubanka wheat.
1913.			
Wheat-grass, western	Agropyron Smithii	1,076±29	2.17±0.06
Brome-grass	Bromus inermis	1,016±26	2.10± .06
Ragweed, western	Ambrosia artemisifolia	948±66	1.91± .13
Vetch, purple	Vicia atropurpurea	935±9	1.89± .03
Flax	Linum usatissimum	905±25	1.82± .05
Marigold, fetid	Boebera papposa	881±26	1.78± .06
Pumpkin	Cucurbita pepo	834±17	1.68± .04
Alfalfa, Grimm	Medicago sativa	834±8	1.68± .02
Soy bean, wild	Glycine soja	815±25	1.64± .05
Clover, crimson	Trifolium incarnatum	805±8	1.62± .02
Lamb's-quarters	Chenopodium album	801±41	1.62± .08
Clover, red	Trifolium repens	789±9	1.59± .02
Bean, horse, S. P. I. 15429	Vicia faba	780±19	1.57± .04
Pea, Canada field	Pisum sativum	775±5	1.56± .02
Sunflower, narrow leaved	Helianthus petiolaris	774±20	1.56± .04
Bean, Mexican	Phaseolus vulgaris	773±8	1.56± .02
Bean, horse, S. P. I. 25645	Vicia faba	772±11	1.56± .03
Squash	Cucurbita maxima	748±8	1.51± .02
Rice, Honduras	Oryza sativa	744±17	1.50± .04
Rape	Brassica napus	743±7	1.50± .02
Potato, McCormick	Solanum tuberosum	717±11	1.45± .03
Cucumber	Cucumbis sativa	713±11	1.44± .03
Sunflower, annual	Helianthus annuus	705±8	1.42± .02
Wheat-grass	Agropyron cristatum	705±27	1.41± .06
Vetch, hairy	Vicia villosa	690±8	1.39± .02
Bean, navy	Phaseolus vulgaris	682±4	1.38± .02
Bean, soy, cultivated	Glycine hispida	672±9	1.35± .02
Potato, Irish Cobbler	Solanum tuberosum	659±15	1.33± .03
Cotton, Triumph	Gossypium hirsutum	657±11	1.33± .03
Alfalfa, Peruvian	Medicago sativa	651±12	1.31± .03
Turnip	Brassica rapa	639±31	1.29± .06
Cantaloupe	Cucumis melo	621±27	1.25± .06
Oat:			
Swedish Select	Avena sativa	617±9	1.24± .02
Burt	do	617±5	1.24± .02
Watermelon	Citrullus vulgaris	600±15	1.21± .03
Cowpea	Vigna sinensis	571±3	1.15± .01
Sunflower, narrow-leaved, from sand hills.	Helianthus petiolaris	570±11	1.15± .03
Cabbage	Brassica oleracea capitata.	539±7	1.09± .02
Wheat, Kubanka	Triticum durum	496±5	1.00
Cocklebur	Xanthium commune	432±13	.87± .03

TABLE XXX.—*Summary of water requirement measurements at Akron, Colo., in 1913, based on dry matter produced*—Continued

Crop and variety.	Botanical name.	Water requirement.	Relative as compared with Kubanka wheat.
1913.			
Corn:			
China White	Zea mays	415±4	0.84±0.01
Bloody Butcher	....do	405±7	.82± .02
Northwestern Dent	....do	399±12	.80± .03
Teosinte, Durango	Euchlene mexicana	390±11	.79± .02
Grass, buffalo and grama	Bulbilis dactyloides and Boutelona gracilis.	389±12	.78± .03
China White×Teosinte		376±4	.76± .01
Corn:			
Hopi	Zea mays	350±8	.71± .02
China White×Hopi	....do	345±3	.70± .01
Indian Flint	....do	342±5	.69± .01
Pigweed	Amaranthus retroflexus	320±7	.65± .02
Grass, buffalo	Bulbilis dactyloides	308±17	.61± .04
Sorghum:			
Minnesota Amber	Andropogon sorghum	298±2	.60± .01
Red Amber	....do	296±1	.59± .01
Purslane	Portulaca oleracea	292±11	.59± .02
Millet, Kursk	Chaetochloa italica	286±4	.58± .01

TABLE XXXI.—*Summary of water-requirement measurements in 1913 based on grain, tubers, roots, or fruit produced*

Crop and variety.	Botanical name.	Water requirement.	Relative water requirement compared with Kubanka wheat.
1913.			
Sunflower:			
Annual	Helianthus annuus	6,384±383	4.83±0.29
Narrow-leaved	Helianthus petiolaris	5,058±132	3.83± .11
Flax	Linum usitatissimum	2,835±52	2.14± .05
Pea, Canada field	Pisum sativum	2,322±121	1.76± .11
Bean, soy	Glycine soja	2,053±51	1.55± .04
Potato, Irish Cobbler	Solanum tuberosum	2,027±197	1.53± .16
Bean, Mexican	Phaseolus vulgaris	1,888±62	1.43± .05
Oats, Swedish Select	Avena sativa	1,876±55	1.41± .04
Cantaloupe	Cucumis melo	1,824±237	1.38± .18
Bean, Navy	Phaseolus vulgaris	1,646±36	1.25± .03
Oats, Burt	Avena sativa	1,641±33	1.24± .03
Cucumber	Cucumis sativa	1,611±67	1.22± .05
Cowpea	Vigna sinensis	1,576±32	1.19± .03
Turnip	Brassica campestris	1,530±132	1.16± .10
Wheat, Kubanka	Triticum durum	1,322±16	1.00
Corn, Northern Dent	Zea mays	1,241±77	.94± .06
Watermelon	Citrullus vulgaris	1,146±49	.87± .04
Sorghum, Red Amber	Andropogon sorgum	1,100±31	.83± .03
Corn, Indian Flint	Zea mays	854±31	.65± .01
Sorghum, Minnesota Amber	Andropogon sorghum	765±12	.58± .01

COMPARISON OF THE WATER REQUIREMENT OF CROPS AT AKRON, COLO., IN 1911, 1912, AND 1913

Climatic conditions at Akron during the summer of 1912 were less severe than during the preceding summer. The rainfall in 1912 was much greater than in 1911, the temperature was lower, and the evaporation was less. These conditions were apparently due in part to a marked reduction in the intensity of the solar radiation at the earth's surface following the eruption of Mount Katmai, Alaska, early in June, 1912, the dust from which produced a haze in the upper atmosphere. Abbot and Fowle (1913) observed a maximum reduction in the solar radiation of about 20 per cent at Bassour, Algeria, and at Mount Wilson, Cal., Kimball (1913a, b) reports an average reduction of 17 per cent in the intensity of the solar radiation at Mount Weather, Va., during the last half of 1912, while Briggs and Belz (1913) have shown that there was a general reduction in the evaporation from a free-water surface during the summer months following the eruption. It is consequently of interest to determine whether the diminution in the intensity of the solar radiation was accompanied by a reduction in the water requirement in 1912. Such a comparison is possible in connection with the Akron experiments, since a large number of the varieties employed in the experiments of 1911 were also included in the 1912 measurements. All varieties showed in 1912 a marked reduction in the water requirement as compared with 1911. The measurements for each year are given in Table XXXII, together with the ratio of the 1912 to the 1911 measurements. The 1912 measurements show an average reduction in the water requirement of 21 ± 2 per cent for the 25 varieties tested during both years. The individual ratios fluctuate somewhat, doubtless owing in part to errors of experiments,[1] but in part also to the different response of individual varieties to changed climatic conditions.

[1] It should be mentioned here that the plants were fertilized in 1912 and not in 1911. This is a matter of importance in this connection, because it is well established that any deficiency in plant food increases the water requirement. The effect of the addition of fertilizer on the water requirement was measured both years. The use of fertilizer resulted in a slight reduction (6 ± 2.3 per cent) in the water requirement of Kubanka wheat at Akron in 1911, comparing pots 7 to 12, fertilized, with pots 1 to 6, unfertilized. These pots stood side by side in the inclosure. (*See* Briggs and Shantz, 1913a, p. 19.) In 1912 the fertilized Kubanka wheat plants showed a slight increase in water requirement—namely, 5 ± 2.3 per cent, comparing pots 1 to 6 against pots 7 to 12. The differences in each instance are without significance when the errors are considered and are furthermore of opposite sign, so that the addition of fertilizer may be considered to have had no effect on the water requirement, so far as Kubanka wheat was concerned. Rich surface soil from the same source was employed in the experiments of both years.

TABLE XXXII.—*Comparison of water-requirement measurements at Akron, Colo., in 1911 and 1912*

Crop.	Water requirement.		Ratio, 1912 to 1911.
	1911.	1912.	
Wheat:			
Kubanka	468±8	394±7	0.84±0.02
Bluestem	531±5	451±4	.85± .01
Spring Ghirka	506±3	457±3	.90± .01
Emmer	534±14	428±3	.80± .02
Oats:			
Sixty-Day	605±5	491±13	.81± .02
Burt	639±7	449±3	.70± .01
Canadian	598±14	399±6	.67± .02
Swedish Select	615±7	423±5	.69± .01
Barley:			
Hannchen	527±8	443±3	.84± .01
Beldi	543±2	416±4	.76± .01
White Hull-less	542±3	439±1	.81± .01
Beardless	544±9	403±8	.74± .02
Rye, spring	724±7	496±9	.69± .01
Corn:			
Northwestern Dent	368±10	280±10	.75± .03
Iowa Silvermine	420±3	302±7	.72± .02
Esperanza	319±5	239±3	.79± .01
Sorghum:			
Red Amber	298±4	237±4	.80± .02
Milo, Dwarf	333±3	273±4	.82± .02
Kafir, Blackhull	278±5	259±5	.93± .02
Durra, White	321±2	255±3	.79± .01
Kaoliang, Brown	301±3	223±1	.74± .01
Millet, German	263±15	248±7	.94± .05
Legumes:			
Alfalfa	1,068±16	659±6	.62± .03
Clover, sweet	709±9	638±4	.90± .02
Beet, sugar	377±8	321±8	.85± .03
Mean water-requirement ratio for 1912 to 1911			.79± .02
Mean evaporation ratio for June, July, and August, 1912 to 1911			.75± .03

Evaporation measurements from a free-water surface at Akron are also available for 1911 and 1912 (Briggs and Belz, 1910, p. 17). The ratio of the evaporation in 1912 to that in 1911 by months is as follows: June, 0.69; July, 0.78; August, 0.79. The average ratio during these three months is 0.75±0.03. This corresponds to a reduction of 25±3 per cent in evaporation as compared with a reduction of 21±2 per cent in the water requirement. The change in the water requirement of these 25 varieties taken together is seen to be in approximate agreement with the change in evaporation from a free-water surface. A consideration of the individual ratios indicates, however, that different varieties may respond quite differently to the same change in climatic conditions.

To investigate further the variation in water requirement due to differences in climatic conditions, a number of varieties were also

included in the measurements of both 1912 and 1913. The ratios of the water requirement of these crops in 1912 to that in 1913 are given in Table XXXIII. Similar ratios are also given for crops grown in 1911 and 1913. It will be seen that the mean 1913–1911 ratio approximates unity; in other words, the mean water requirement of the crops under investigation was practically the same for both years. The water requirement in 1912 is seen to be far below the 1913 value, the mean ratio being 0.75±0.01. The mean ratio of the monthly evaporation for June, July, and August, 1912, compared with 1913, is 0.80±0.02, which is in approximate agreement with the ratio of the water requirement of crops grown during the two years.

The crops at Akron as influenced by climatic conditions in 1911, 1912, and 1913 may then be summarized as follows:

TABLE XXXIII.—*Comparison of the water requirement of the same crops at Akron, Colo., 1911, 1912, and 1913*

Crop.	Water requirement.				
	1911.	1912.	1913.	Ratio.	
				1913 to 1911.	1913 to 1912.
Wheat, Kubanka	468±8	394±7	496±5	1.06	0.80
Oats:					
Swedish Select	615±7	423±5	617±9	1.00	.69
Burt	639±7	449±3	617±5	.97	.73
Corn:					
Northwestern Dent	368±10	280±10	399±12	1.08	.70
Hopi		285±7	358±8		.80
China White		315±7	416±4		.76
Sorghum:					
Minnesota Amber		239±2	298±2		.80
Red Amber	298±4	237±4	296±1	.99	.80
Millet, Kursk		187±2	286±4		.66
Legumes:					
Alfalfa, Grimm	1,068±16	657±11	834±8	.77	.79
Pea, Canada field	800±17		775±5	.97	
Potato, Irish Cobbler	448±11		659±15	1.47	
Cotton		488±14	657±11		.75
Rice		496±9	744±17		.67
Mean water requirement ratio				1.04±.04	.75±01
Evaporation in inches for three summer months	28.46	21.42	26.75	.94±.04	.80±02

The conditions during 1911 and 1913 were such as to give rise to practically the same water requirement. The water requirement of crops grown in 1912 was on the average only 79±2 per cent of crops grown in 1911 and 75±2 per cent of crops grown in 1913. Therefore, in order to determine the relative water requirement of the different crops, it appears justifiable to increase the 1912 water requirement ratios by the reciprocal of 0.77—namely, 1.3. This procedure has been followed in the summary

table (Table XXXIV), which places the water requirement of all crops upon the basis of years similar to 1911 and 1913. When the water-requirement measurement of any particular crop extended over more than one year, the mean value of the several water-requirement determinations is given in Table XXXIV.

SUMMARY

This paper deals with the measurement of the water requirement of plants at Akron, Colo., in the central portion of the Great Plains. The term "water requirement" is here used to express the ratio of the water absorbed by a plant during its period of growth to the dry matter produced. The plants were grown to maturity in large galvanized-iron pots having a capacity of about 115 kg. of soil. Each pot was provided with a tight-fitting cover having openings for the stems of the plants, the annular space between the stem of the plant and the cover being sealed with wax. The loss of water was thus practically confined to that taking place through transpiration, and the entrance of rainfall was almost wholly prevented. The pots were weighed two or three times weekly to determine the amount of water required to maintain normal weight. Water was delivered from 2-liter calibrated flasks through stoppered openings in the middle of the cover to a 5-inch flowerpot sunk in the soil immediately beneath the cover.

To protect the plants from birds and severe wind and hail storms, it was found necessary to conduct the experiments in a screened inclosure. Pyrheliometric measurements showed that the inclosure reduced the radiation about 20 per cent. Water-requirement measurements conducted simultaneously with the same plants inside and outside the inclosure showed that the inclosure also reduced the water requirement approximately 20 per cent.

Rich surface soil was used in the pots, and the pots were also fertilized to insure an adequate supply of plant food. Six pots of plants of each variety were used, and the water requirement of each pot was determined independently, in order to provide a basis for the determination of the probable errors of the experiment.

The detailed results given in the paper comprise measurements of 44 species and varieties in 1912 and 55 in 1913. The writers' 1911 measurements have also been included in the summary table. The years 1911 and 1913 were similar in character, and the same plants grown during both years gave practically the same water requirement. The year 1912 was cooler and the evaporation and light intensity were much lower. These conditions had a marked influence on the water requirement, the mean water requirement in 1912 being only 77 per cent of that in 1911 and 1913. In order to place all of the determinations upon a comparative basis, the 1912 measurements have accordingly been increased 30 per cent in the summary table (Table XXXIV).

TABLE XXXIV.—*Summary of water-requirement determinations at Akron, Colo., in 1911, 1912, and 1913, based on the production of dry matter*

Plant.	Botanical name.	Number of observations.	Water requirement.	
			Of species or variety.	Mean of genus.
GRAIN CROPS.				
Proso:		*Years.*		
Voronezh, C. I. 16	Panicum miliaceum	1	268±1	
Tambov, S. D. 366	do	1	270±1	293
Black Voronezh, S. D. 334	do	1	341±10	
Millet:				
Kursk, S. P. I. 30029	Chaetochloa italica	1	261±15	
Kursk, S. P. I. 34771	do	2	265±3	
Kursk, S. P. I. 22420	do	1	287±2	310
German, S. P. I. 26845	do	2	293±9	
Turkestan, S. P. I. 20694	do	1	444±9	
Sorghum:				
Kafir, Dwarf Blackhull, C. I. 340.	Andropogon sorghum	1	285±3	
Kaoliang, Brown, S. P. I. 24993.	do	2	296±2	
Kafir, White, C. I. 370	do	1	297±4	
Red Amber, S. P. I. 17563	do	3	301±2	
Kafir, Early Blackhull, C. I. 472.	do	1	302±13	
Minnesota Amber, A. D. I. 341–13.	do	2	305±2	
Kafir, Blackhull, S. P. I. 24975.	do	2	308±4	322
Milo, White, C. I. 365	do	1	317±3	
Kafir×Durra, C. I. 198–15–3.	do	1	321±5	
Feterita, C. I. 182	do	1	323±4	
Milo, S. P. I. 24960	do	1	324±4	
Durra, White, S. P. I. 24997.	do	1	327±2	
Milo, Dwarf, S. P. I. 24970.	do	2	344±3	
Sudan grass, S. P. I. 25071.	do	1	467±9	
Corn:				
Esperanza	Zea mays	2	315±3	
China White×Esperanza	do	1	325±2	
Indian Flint	do	1	342±5	
China White×Hopi	do	1	345±3	
Hopi	do	2	361±6	
China White×Laguna	do	1	376±5	368
Northwestern Dent	do	3	377±7	
Laguna	do	1	384±8	
Bloody Butcher	do	1	405±7	
Iowa Silvermine	do	2	407±5	
China White	do	2	413±5	
Teosinte:				
China White×Teosinte		1	376±4	383
Teosinte	Euchlaena mexicana	1	390±11	
Wheat:				
Turkey, C. I. 1571	Triticum aestivum	1	473±8	
Kharkov, C. I. 1583	do	1	475±8	
Kubanka, C. I. 1440	Triticum durum	3	492±4	
Galgalos, C. I. 2398	Triticum aestivum	1	496±4	513
Emmer, C. I. 2951	Triticum dicoccum	2	545±7	
Spring Ghirka, C. I. 1517	Triticum aestivum	2	550±3	
Marvel Bluestem, C. I. 3082	do	2	559±4	

TABLE XXXIV.—*Summary of water-requirement determinations at Akron, Colo., in 1911, 1912, and 1913, based on the production of dry matter*—Continued

Plant.	Botanical name.	Number of observations.	Water requirement. Of species or variety.	Water requirement. Mean of genus.
GRAIN CROPS—continued.				
Barley:		*Years.*		
Hannchen, C. I. 531	Hordeum distichon	2	502±4	534
Beardless, C. I. 716	Hordeum vulgare	2	534±7	
Beldi, C. I. 190	.....do	2	542±3	
White Hull-less, C. I. 595	.....do	2	556±2	
Buckwheat	Fagopyrum fagopyrum	1	578±13	578
Oats:				
Canadian, C. I. 444	Avena sativa	2	559±8	597
Swedish Select, C. I. 134	.....do	3	594±4	
Burt, C. I. 293	.....do	3	613±3	
Sixty-Day, C. I. 165	.....do	2	622±9	
Rye, spring, C. I. 73	Secale cereale	2	685±7	685
Rice, Honduras, C. I. 1643	Oryza sativa	2	710±15	710
Flax, North Dakota, No. 155	Linum usitatissimum	1	905±25	905
OTHER CROPS.				
Beet, sugar:				
Morrison-grown Kleinwanzleben.	Beta vulgaris	2	397±6	397
Potato:				
Irish Cobbler	Solanum tuberosum	2	554±9	636
McCormick	.....do	1	717±11	
Crucifers:				
Cabbage, Early Jersey, Wakefield.	Brassica oleracea capitata	1	539±7	640
Turnip, Purple-top	Brassica rapa	1	639±31	
Rape	Brassica napus	1	743±7	
Cotton, Triumph	Gossypium hirsutum	2	646±11	646
Cucurbits:				
Watermelon, Rocky Ford	Citrullus vulgaris	1	600±15	600
Cantaloupe, Rocky Ford	Cucumis melo	1	621±27	667
Cucumber, Boston Pickling	Cucumis sativa	1	713±11	
Squash, Hubbard	Cucurbita maxima	1	748±8	791
Pumpkin, common field	Cucurbita pepo	1	834±17	
Legumes:				
Cowpea, S. P. I. 29282	Vigna sinensis	1	571±3	571
Chick-pea, S. P. I. 24322	Cicer arietinum	1	663±18	663
Bean, navy	Phaseolus vulgaris	1	682±4	728
Bean, Mexican	.....do	1	773±8	
Bean, soy, S. P. I. 21755	Glycine hispida	1	672±9	744
Bean, soy (wild), S. P. I. 25138.	Glycine soja	1	815±25	
Clover, sweet, S. P. I. 21216	Melilotus alba	2	770±5	770
Pea, Canada field, S. P. I. 30134.	Pisum sativum	1	775±5	788
Pea, Canada field, S. P. I. 22637.	.....do	1	800±17	
Vetch, hairy, S. P. I. 34298	Vicia villosa	1	690±8	794
Bean, horse, S. P. I. 25645	Vicia faba	1	772±11	
Bean, horse, S. P. I. 15429	.....do	1	780±10	
Vetch, purple, S. P. I. 18131.	Vicia atropurpurea	1	935±9	
Clover, red, S. P. I. 34869	Trifolium repens	1	789±9	797
Clover, crimson, S. P. I. 33742.	Trifolium incarnatum	1	805±8	

TABLE XXXIV.—*Summary of water-requirement determinations at Akron, Colo., in 1911, 1912, and 1913, based on the production of dry matter*—Continued

Plant.	Botanical name.	Number of observations.	Water requirement. Of species or variety.	Water requirement. Mean of genus.
OTHER CROPS—continued.				
Legumes—Continued.		*Years.*		
Alfalfa, Peruvian, S. P. I. 30203.	Medicago sativa	1	651±12	831
Alfalfa, Grimm, A. D. I. E-23-20-52.	....do	2	844±8	
Alfalfa, yellow-flowered	Medicago falcata	1	865±18	
Alfalfa, Grimm, S. P. I. 25695.	Medicago sativa	2	963±9	
Grasses:				
Wheat-grass	Agropyron cristatum	1	705±27	861
Brome-grass	Bromus inermis	1	1,016±26	
NATIVE PLANTS.				
Tumbleweed	Amaranthus graecizans	1	277±4	287
Pigweed	Amaranthus retroflexus	2	297±4	
Purslane	Portulaca oleracea	1	292±11	292
Grass, buffalo	Bulbilis dactyloides	1	308±17	308
Thistle, Russian	Salsola pestifer	1	336±5	336
Grass, buffalo and grama	Bulbilis dactyloides. Bouteloua gracilis	1	389±12	389
Cocklebur	Xanthium commune	1	432±13	432
Gumweed	Grindelia squarrosa	1	608±23	608
Sage, mountain	Artemisia frigida	1	616±18	616
Sunflower (Akron)	Helianthus petiolaris	1	774±20	683
Sunflower (sand hills)	....do	1	570±11	
Sunflower	Helianthus annuus	1	705±8	
Lamb's-quarters	Chenopodium album	1	801±41	801
Marigold, fetid	Boebera papposa	1	881±26	881
Ragweed, western	Ambrosia artemisifolia	1	948±06	948
Wheat-grass, western	Agropyron Smithii	1	1,076±29	1,076

The results given in the summary table (Table XXXIV) therefore represent the water requirement of the plants for years similar to 1911 and 1913, when grown in a screened inclosure, which reduces the solar radiation to 80 per cent of its normal value. According to measurements made with wheat, alfalfa, and cocklebur, the removal of the inclosure would increase the water requirement as given in the table by 25 per cent. The plants grown outside the inclosure were isolated and freely exposed, while plants under field conditions mutually protect and shade one another to some extent. Comparison with wheat plants grown in pots sunk in trenches indicates that the inclosure measurements, at least in the case of wheat, are less than 10 per cent below the water requirement of plants exposed under field conditions.

The measurements in Table XXXIV represent the relative water requirement of the different plants tested, subject to the limitations imposed by the difference in the growth period of the plants. The

measurements in 1912 would also indicate that the character of the season influences the water requirement of some plants more than others. For this reason, where the results of two or more years have been combined in the table, the probable error has been confined to the errors of experiment and does not include the fluctuations in water requirement due to the season.

In order to facilitate comparison, the plants have been arranged under three main heads: Grain crops, other crops, and native plants. Under "Grain crops" are also included certain sorghums and millets which are usually grown for forage. Under the heading "Other crops" are included principally the legumes, cucurbits, crucifers, sugar beets, cotton, and potatoes, as well as some of the introduced grasses. Under the heading "Native plants" are listed indigenous species, as well as certain introduced species which have become thoroughly established.

The grain crops fall rather naturally into two sections: Those of low water requirement—proso, millet, sorghum, and corn—and those of high water requirement—wheat, barley, oats, rye, and flax. The plants with a comparatively low water requirement are late-maturing crops, which make their best growth during the hottest and driest portion of the summer. The plants having a comparatively high water requirement mature during midsummer and make their best growth during the earlier, cooler period of the year. The range in water requirement of the first group is from 261 for Kursk millet to 468 for Sudan grass, while the range in the second group is from 473 for Turkey wheat to 905 for flax.

Representing the water requirement of proso as 1, the water requirement of the grain crops is as follows: Millet, 1.06; sorghum, 1.10; corn, 1.26; teosinte, 1.34; wheat, 1.76; barley, 1.83; buckwheat, 1.98; oats, 2.04; rye, 2.34; rice, 2.42; and flax, 3.38. In other words, flax requires more than three times as much water and rice more than twice as much water as proso and millet in producing a pound of dry matter.

In the second group sugar beet ranks first, having a water requirement almost as low as corn. Potato ranks next, followed by crucifers, cucurbits, legumes, and grasses, in order. A wide range is shown in each of these families. The groups as a whole show a range somewhat less than the grain groups.

Representing the water requirement of sugar beet as 1, the values for the "Other crops," exclusive of the legumes, are as follows: Cabbage, 1.36; Irish Cobbler potato, 1.39; watermelon, 1.51; cantaloupe, 1.57; turnip, 1.60; cotton, 1.63; cucumber, 1.80; wheat-grass, 1.85; rape, 1.87; squash, 1.89; pumpkin, 2.10; and brome-grass, 2.56.

The cowpea was the most efficient of the legumes. Representing its water requirement by 1, that of the other legumes is as follows: Peruvian alfalfa, 1.14; chick-pea, 1.16; soy bean, 1.18; navy bean, 1.20; hairy vetch, 1.21; sweet clover, 1.35; Mexican bean, 1.35; horse bean, 1.36; red clover, 1.38; Canada field pea, 1.38; crimson clover, 1.41; wild soy

bean, 1.42; select Grimm alfalfa, 1.48; yellow-flowered alfalfa, 1.51; purple vetch, 1.64; and unselected Grimm alfalfa, 1.69.

The native plants show a range in water requirement greater even than the cultivated crops. Amaranths, buffalo and grama grasses, purslane, and Russian thistle have a low water requirement and compare favorably with millet and sorghum, while sunflower, fetid marigold, western ragweed, and western wheat-grass have a high water requirement about equal to that of alfalfa.

Representing the water requirement of tumbleweed (*Amaranthus graecizans*) as unity, the water requirement of these native plants is as follows: Purslane, 1.05; pigweed, 1.07; buffalo grass, 1.11; Russian thistle, 1.21; buffalo and grama grasses, 1.40; cocklebur, 1.56; gumweed, 2.20; mountain sage, 2.22; sunflower, 2.56; narrow-leaved sunflower, 2.80; lamb's-quarters, 2.89; fetid marigold, 3.18; western ragweed, 3.42; western wheat-grass, 3.89.

Varieties of the same crop often differ widely in water requirement. In the case of barley, the variety having the highest water requirement was 8 per cent above the lowest; oats, 11 per cent; wheat, 18 per cent; proso, 27 per cent; corn, 31 per cent; vetch, 35 per cent; alfalfa, 48 per cent; sorghum, 60 per cent; and millet, 70 per cent. This wide range in water requirement among the varieties of many crops encourages the belief that strains may yet be secured which are still more efficient in the use of water than those now grown in dry-land regions.

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PLATE I

Fig. 1.—General view of the plant inclosure used at Akron, Colo., showing the pipe framework covered with a hail screen, with the board base surmounted by a single width of cheesecloth to protect the plants against high winds. Photographed on July 15, 1912.

Fig. 2.—General view inside the inclosure, showing the arrangement of pots and general conditions of growth. Corn and sorghums are shown in the foreground, small grain in the background. Photographed on July 3, 1912.

Fig. 3.—General view of the inclosure photographed shortly after the grain in some of the pots had been harvested. Photographed on September 4, 1912.

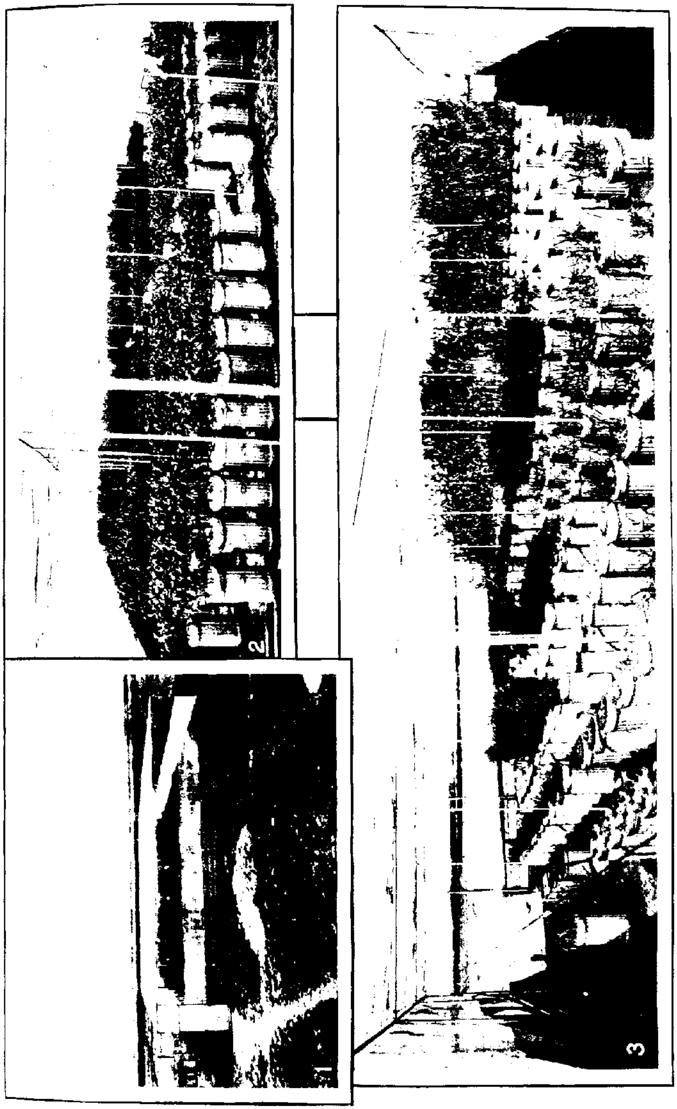


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PLATE II

Fig. 1.—Pot planted with sugar beets, showing the wax seal around the plants and also the sealed holes where stand was not perfect.

Fig. 2.—Weighing pots, showing spring balance, weighing support, and general procedure. Two men operate the weighing support, one of whom lifts the pot by means of a windlass, while a third reads the balance and records the weight. By this method weighings can be made at the rate of two per minute.

Fig. 3.—*Grindelia squarrosa* (gumweed) at left (pot 164), and *Artemisia frigida* (mountain sage) at right (pot 167), illustrating the growth of native plants used in the water-requirement measurements. Photographed on July 29, 1912. Water requirement of Grindelia, 468±18; of Artemisia, 474±14.

60300°—14——5

PLATE III

Fig. 1.—Kubanka wheat (pots 1 to 6), grown May 9 to September 3, 1912. Photographed on July 19, 1912. Water requirement, 394±7.

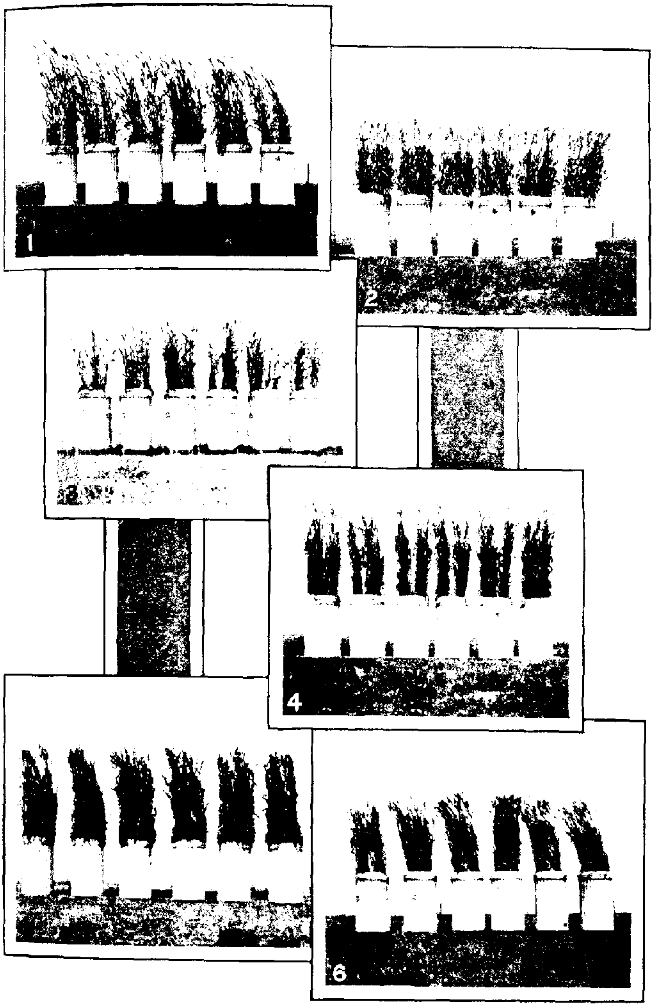
Fig. 2.—White Hull-less barley (pots 103 to 108), grown May 16 to August 12, 1912. Photographed on July 19, 1912. Water requirement, 439±1.

Fig. 3.—Kubanka wheat (pots 12 to 18). Set grown outside of shelter, May 9 to August 31, 1912. Photographed on July 26, 1912. Water requirement 507±13.

Fig. 4.—Emmer (pots 61 to 66), grown May 11 to August 12, 1912. Photographed on July 19, 1912. Water requirement, 428±3.

Fig. 5.—Swedish Select oats (pots 85 to 90), grown May 17 to August 23, 1912. Photographed on July 26, 1912. Water requirement, 423±5.

Fig. 6.—Kharkov wheat (pots 37 to 42), grown April 27 to August 28, 1912. Photographed on July 29, 1912. Water requirement, 365±6.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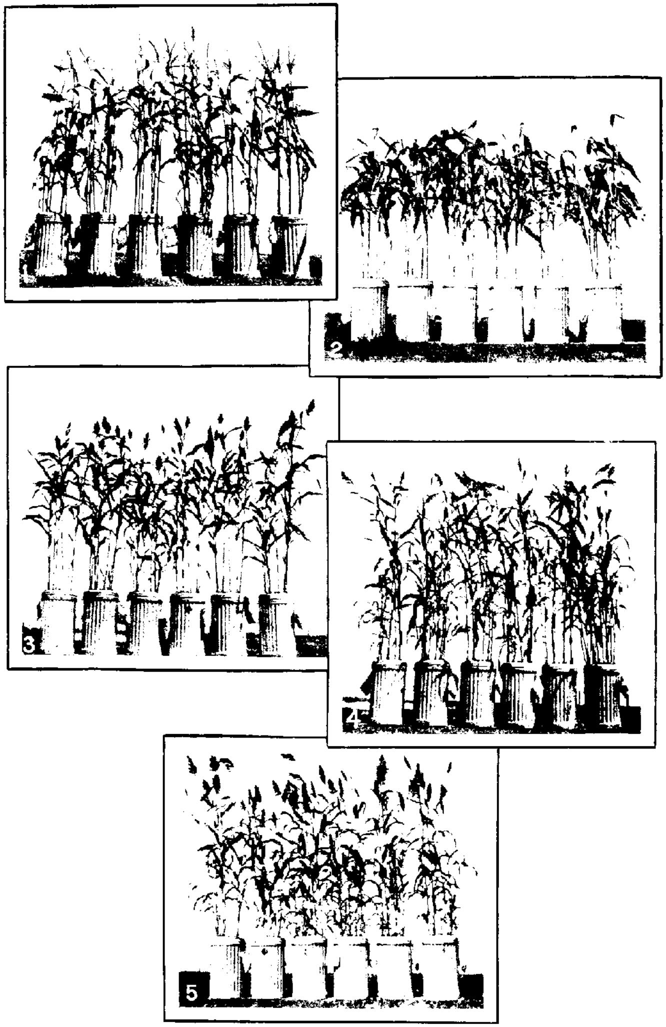
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PLATE IV

Fig. 1.—Northwestern Dent corn (pots 277 to 282), grown June 9 to September 16, 1912. Photographed on September 6, 1912. The lower leaves were picked off as they became dry and placed in bags attached to the pots, thus avoiding loss of dry matter. Water requirement, 280 ± 10.

Fig. 2.—Hopi corn (pots 295 to 300), grown June 12 to September 26, 1912. Photographed on September 9, 1912. The lower leaves were picked off as they became dry and placed in bags attached to the pots. Water requirement, 285 ± 7.

Fig. 3.—White durra (pots 235 to 240), grown June 9 to September 26, 1912. Photographed on September 6, 1912. The lower leaves were removed as soon as they became dry and placed in bags attached to the pots. Water requirement, 255 ± 3.

Fig. 4.—Red Amber sorghum (pots 253 to 258), grown June 29 to September 27, 1912. Photographed on September 7, 1912. Water requirement, 237 ± 4.

Fig. 5.—Minnesota Amber sorghum (pots 247 to 252), grown June 9 to September 26, 1912. Photographed on September 9, 1912. Water requirement, 239 ± 2.

PLATE V

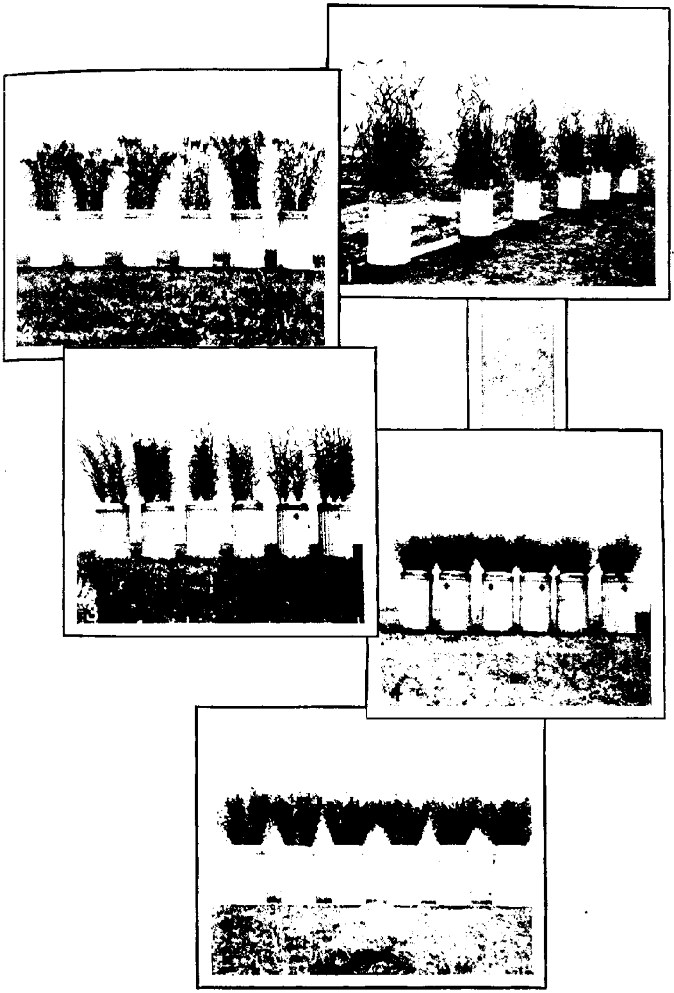
Fig. 1.—Sudan grass (pots 211 to 216). First crop, grown May 28 to July 26, 1912. Photographed on July 25, 1912. Water requirement, 312±3.

Fig. 2.—Voronezh proso (pots 199 to 204), grown June 5 to August 20, 1912. Photographed on July 29, 1912. Water requirement, 206±1.

Fig. 3.—Kursk millet (pots 205 to 210), grown June 9 to August 20, 1912. Photographed on July 30, 1912. Water requirement, 187±2.

Fig. 4.—Select Grimm alfalfa (pots 139 to 144), grown in the open, May 24 to July 27, 1912. Photographed on July 26, 1912. Water requirement, 745±22.

Fig. 5.—Select Grimm alfalfa (pots 133 to 138), grown in the shelter, May 24 to July 26, 1912. Photographed on July 26, 1912. Water requirement, 600±17.



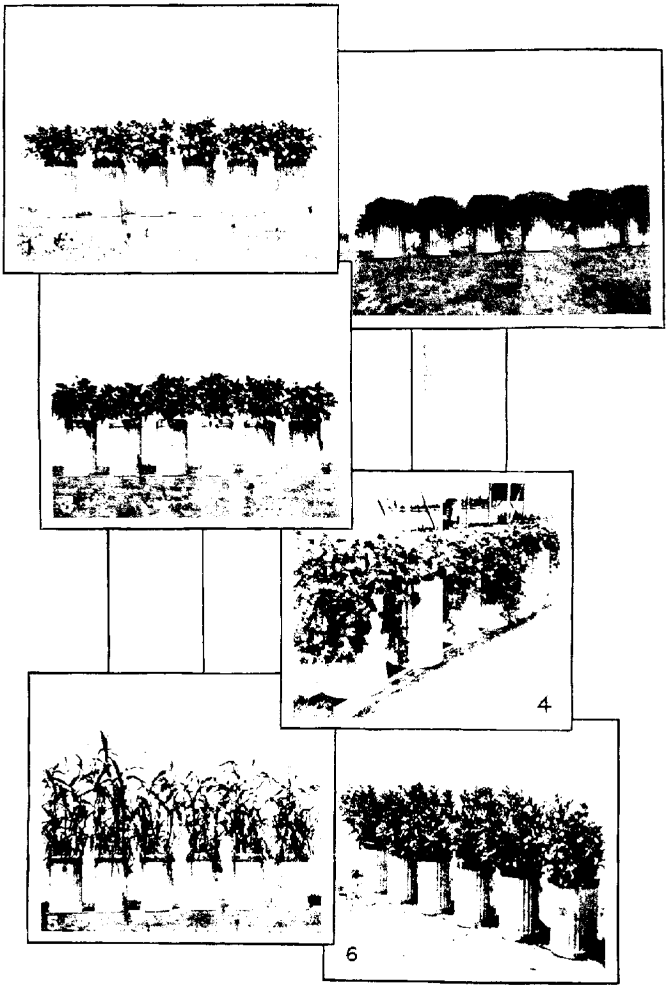

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PLATE VI

Fig. 1.—Cowpea (pots 151 to 156), grown June 17 to August 26, 1913. Photographed on July 26, 1913. Water requirement, 571±3.

Fig. 2.—Hairy vetch (pots 181 to 186), grown May 29 to July 18, 1913. Photographed on July 17, 1913. Water requirement, 672±9.

Fig. 3.—Soy bean (pots 193 to 198), grown June 1 to August 26, 1913. Photographed on July 26, 1913. Water requirement, 690±8.

Fig. 4.—Cantaloupe (pots 325 to 330), grown June 14 to September 13, 1913. Photographed in place on July 26, 1913. Water requirement, 778±34.

Fig. 5.—Indian Flint corn (pots 253 to 258), grown June 7 to August 27, 1913. Photographed on July 26, 1913. Water requirement, 342±5.

Fig. 6.—McCormick potato (pots 121 to 126), grown June 5 to October 4, 1913. Photographed on July 26, 1913. Water requirement, 717±11.

PLATE VII

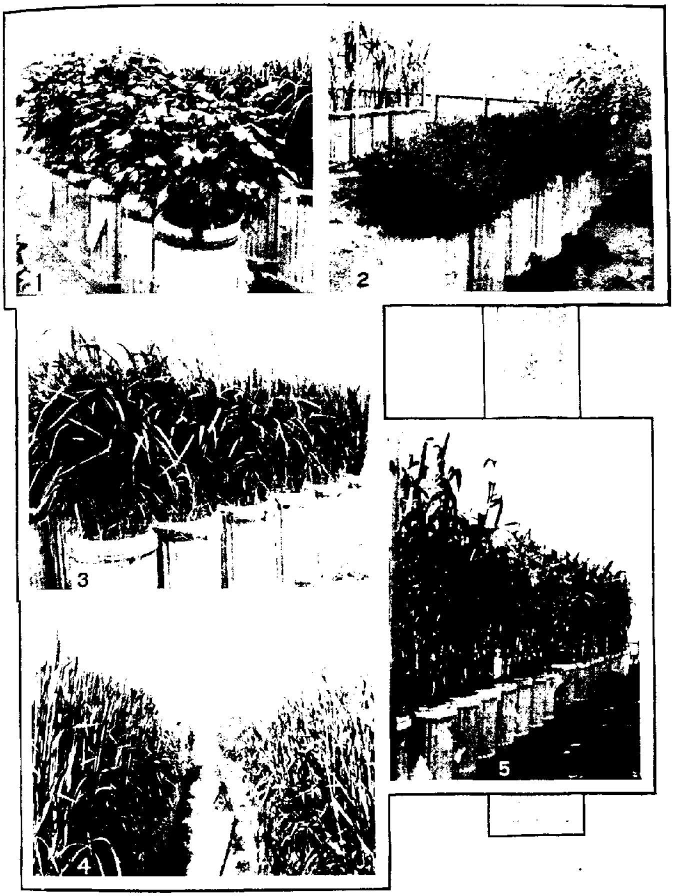
Fig. 1.—Triumph cotton in shelter (pots 163 to 168), grown May 29 to September 16, 1913. Photographed on September 15, 1913. Water requirement, 657 ± 11.

Fig. 2.—*Boebera papposa*, grown July 25 to September 17, 1913. Photographed on September 15, 1913. Water requirement, 881 ± 26. *Helianthus petiolaris* in background.

Fig. 3.—Rice in shelter (pots 157 to 162), grown June 12 to September 16, 1913. Photographed on September 15, 1913. Water requirement, 744 ± 17.

Fig. 4.—General view of the shelter, showing emmer at the left and White Hull-less barley at the right. Photographed on July 3, 1912.

Fig. 5.—General view in the shelter, showing corn in the foreground. Photographed on September 6, 1912.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HEART-ROT OF OAKS AND POPLARS CAUSED BY POLYPORUS DRYOPHILUS

By GEORGE G. HEDGCOCK, *Pathologist*, and W. H. LONG, *Forest Pathologist, Investigations in Forest Pathology, Bureau of Plant Industry*

INTRODUCTION

The oaks (*Quercus* spp.) of the United States are diseased by a number of species of fungi which attack the heartwood. Von Schrenk and Spaulding (1909)[1] briefly described some of these diseases and also a piped rot of the heartwood of oaks and chestnuts (*Castanea dentata*) the cause of which was unknown to them. In 1909, the senior writer found *Polyporus dryophilus* constantly associated with a whitish piped rot of several species of oaks in the southwestern and western United States. This rot was much like that described by Von Schrenk and Spaulding and was identical with that of specimens in oak collected by them. Later observations by the senior writer established the causal relation of *Polyporus dryophilus* to this piped rot.

The junior writer in 1913 found a second form of piped rot caused by *Polyporus pilotae* in the heart-wood of the root and basal portion of the trunks of oaks and also in chestnuts. This was identical with the rot in chestnut trees figured and collected by Von Schrenk and Spaulding.

The oaks of the southwestern and western United States are not used to any extent for lumber and timbers and are, as a rule, valuable only for fuel. This is due to the rotted condition of the heartwood in the larger and older trees. For example, the trunks of the valley oak (*Quercus lobata*),[2] which attains a large size in the valleys of central California, are usually either badly decayed or hollow and are of no value except for the poor grade of fuel they furnish. The senior writer in 1909 ascertained that *Polyporus dryophilus* was the chief cause of the deterioration of the oaks of the western United States. Meinecke (1914) reports a destructive heart-rot of oaks caused by this fungus in California and Nevada, and data by him will be cited in the section on the distribution of the fungus. In Arizona and New Mexico the oaks are diseased in the heartwood nearly as badly as in California and Oregon, and *P. dryophilus* is the common cause of decay. In these States oaks are usually small and are valuable only for fuel.

In Texas and the adjacent States of Oklahoma and Arkansas the piped rot produced by this fungus is very common, and among other

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 77.

[2] The nomenclature for trees used in this paper is that of George B. Sudworth (1898).

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species the valuable white oak (*Quercus alba*) is commonly attacked. To the east and north the fungus has been found less frequently, but it occurs in many sections.

From observations and estimates *Polyporus dryophilus* ranks with the most common heart-rotting fungi which attack the oaks. In 1912 the senior writer found aspens (*Populus tremuloides*) in Colorado attacked by this fungus. It apparently is not commonly found on this host.

PIPED ROT CAUSED BY POLYPORUS DRYOPHILUS

The whitish piped rot caused by *Polyporus dryophilus* has been found by the writers to be directly associated with the sporophores of this fungus in the following 15 species of trees: *Quercus alba, Q. arizonica, Q. californica, Q. digitata, Q. emoryii, Q. gambelii, Q. garryana, Q. marilandica, Q. minor, Q. prinoides, Q. prinus, Q. texana, Q. velutina, Q. virginiana,* and *Populus tremuloides*.

PIPED ROT IN THE WHITE OAK

MACROSCOPIC CHARACTERS

The first indication of the whitish piped rot in white oak is a discoloration of the heartwood, which assumes a water-soaked appearance (Pl. VIII, fig. 1). This "soak" may extend from 1 to 10 feet beyond the actually rotting region where delignification is occurring. When dry, this water-soaked heartwood becomes hazel to tawny in color. The next stage of the rot is one of delignification, which usually begins alongside of and following more or less regularly the medullary rays, thus producing a mottled appearance of the wood in radial view (Pl. VIII, figs. 2, 5, and 6). This type of the rot is very common in the medium-sized branches (6 to 12 inches in diameter) and in the early stages of the disease in the bole of the tree. In final stages the diseased wood is firm, has a white, stringy appearance (Pl. VIII, figs. 3 and 4) and consists of white cellulose strands of delignified wood fibers and other wood structures bounded by areas of apparently sound but actually slightly diseased and discolored heartwood. Cinnamon-brown areas are scattered throughout the oldest rotted wood (Pl. VIII, fig. 3). These areas are especially common and abundant in the vicinity of sporophores and along checks or openings through the sapwood. The rot immediately adjacent to a sporophore is therefore often cinnamon brown to russet in color. No cavities large enough to be seen by the naked eye are produced by this rot, but much of the white cellulose is finally absorbed, leaving minute irregular cavities in the wood.

MICROSCOPIC CHARACTERS

Delignification usually begins in the wood fibers lying next to the vessels in the spring wood and adjacent to the large medullary rays. The solvents secreted by this fungus apparently are able to delignify all of the

elements of the wood. All, or only the outer rows, of cells of the large medullary rays may be delignified, the middle lamellæ dissolved, and the completely delignified cell membranes partially absorbed.

Isolated areas between the large medullary rays may also be delignified. The cells of some of the medullary rays and of the wood parenchyma often contain starch grains even after the absorption of a portion of the inclosing cell walls. A ferruginous substance is also present in many of the cells of the small medullary rays, in the lumen of the wood fibers, and even in some of the other wood structures. Many of the vessels adjacent to each large medullary ray contain hyaline branching hyphæ 0.5 to 1 μ in diameter. The association of the delignified areas with the medullary rays is readily seen in a cross section of the wood where delignification is just beginning, but later in the more advanced stages of the rot this association is not so evident when the delignification of the wood fibers has become general throughout the rotting area. The early absorption of portions of the delignified tissue prevents the formation of long continuous strands of cellulose fibers, although in a tangential view irregular white lines may be seen which consist of fragments of the delignified cells (Pl. VIII, fig. 5). In very advanced stages of the rot near the center of the tree white longitudinal lines are seen in a radial view (Pl. VIII, fig. 4). These usually consist of remnants of partially absorbed cellulose fibers bound together by strands of white mycelium, which also fill the vessels and the minute cavities left by the absorption of the delignified tissue.

PIPED ROT IN CHESTNUT OAK

The rot produced by *Polyporus dryophilus* in the chestnut oak (*Quercus prinus*) is slightly different from that in white oak. The diseased wood is hazel in color, with very narrow concentric zones of ivory-yellow cellulose. These zones are adjacent to the large spring vessels of each year and consist of the delignified wood fibers of this tissue. The large vessels in radial-longitudinal view are seen, even under a hand lens, to be filled with cobwebby strands of colorless hyphæ. It is in the tissue adjacent to such hyphæ-filled vessels where the delignification is most pronounced.

PIPED ROT IN THE WESTERN OAKS

The rot caused by *Polyporus dryophilus* in these oaks differs but little from that found in the white oak. The mottled appearance of the rot in its earlier stages is not so pronounced. In the final stage of the rot, after a very large proportion of all the elements is delignified, there is but little apparently sound heartwood. In the older rot in the center of the heartwood the white color by far exceeds the brown, of which there is very little.

PIPED ROT IN EUROPEAN OAKS

Robert Hartig (1878), in his epoch-making work on the true nature of the rots of woods, described a whitish heart-rot of the oak, which he attributed to *Polyporus dryadeus*. A careful study of Hartig's figures, and the description of the sporophore which he found associated with the white heart-rot so accurately described by him, is sufficient to convince anyone who is familiar with the true *P. dryadeus* that Hartig's fungus was not *P. dryadeus*. It is undoubtedly identical with the heart-rotting fungus known in America as *P. dryophilus* and found by the senior author to be associated with a whitish piped rot in oak. Through the kindness of Dr. Von Tubeuf the junior writer obtained a piece of the original rot (Pl. VIII, figs. 7 and 8) which Robert Hartig (1878) ascribed to *P. dryadeus*. A careful study of this specimen showed that it is identical in every respect with the rot produced by *P. dryophilus* in the white oak. There is also another European specimen (Pl. VIII, fig. 9) of this rot in oak in the Laboratory of Forest Pathology, of the Department of Agriculture, which has all the characters of the rot produced by *P. dryophilus*.

CHARACTERS OF PIPED ROT COMMON TO ALL SPECIES OF OAKS

The rots produced by *Polyporus dryophilus* in all the species of oak examined had the following characters in common: (1) A water-soaked discolored area in the first stage (Pl. VIII, fig. 1); (2) a general association of the earlier delignification with the medullary rays (Pl. VIII, figs. 5 and 6); (3) later a more general delignification of all the wood fibers (Pl. VIII, fig. 3); (4) the formation of white mycelial longitudinal lines (Pl. VIII, fig. 4); (5) the presence of cinnamon-brown areas in the older rotted wood (Pl. VIII, fig. 3). These brown patches, ranging from 2 by 4 mm. up to 10 by 35 mm. in size, consist of fragments of wood interwoven with ferruginous, thick-walled, septate hyphæ, which easily break into short pieces. The hyphæ are about 3μ thick, have many short (3 to 8μ) branches, and are mixed with various sizes of hyphæ down to 1μ or less in diameter, the smaller of which are hyaline.

HEART-ROT PRODUCED BY POLYPORUS DRYOPHILUS IN ASPEN

The description of the heart-rot which follows was made from the diseased wood of a dead aspen (*Populus tremuloides*) bearing the sporophores of *Polyporus dryophilus*.

MACROSCOPIC CHARACTERS

The general color of the diseased wood varies from a light buff to a maize yellow. In a cross section the rotted wood shows alternating concentric zones of light buff and ochraceous tawny. The light-colored zones consist of the vessels and wood fibers which have been the most vigorously attacked by the solvents of the fungus. The ochraceous-

tawny zones consist of vessels, cells of wood parenchyma, and other elements of the wood in the cells of which a ferruginous amorphous substance has been deposited. These cells are not as strongly attacked by the fungus as are those of the light zones. The rotted wood easily splits into concentric layers, the cleavage usually occurring along the boundary between the white and dark zones. In a tangential view, small, more or less isolated areas of delignified wood fibers may be seen. These delignified fibers are most abundant in the older, rotted portion. In the vicinity of the sporophores the typical cinnamon-brown areas seen in the oak are also present. The rotted wood is soft, almost silky to the touch, is very light in weight, and is easily broken into fragments between the fingers.

MICROSCOPIC CHARACTERS

The vessels in the light-colored zone have very thin walls, owing to the action of the fungus; the bordered pits are often eroded until only large irregularly shaped holes are left and the middle lamellæ of the vessels and of the wood fibers in this region are dissolved. The wood fibers and some of the adjacent cells are finally delignified and absorbed. The delignification occurs most rapidly along the boundary lines between the light-colored and dark-colored zones, along which the cleavage commonly occurs. The small amount of delignified fibers present and their rather rapid absorption prevent the formation of the large areas of white cellulose which are so common in the rot produced by this fungus in oak. In the zone of cleavage cobwebby masses of white mycelium occur which fill the vessels and the small cavities left by the absorption of the wood fibers. The medullary rays are readily attacked by the solvents of this fungus and usually have completely disappeared by the time the final stage of the rot is reached.

ENTRANCE OF THE ROT IN THE HOST

Polyporus dryophilus, so far as known to the writers, gains entrance in the wood of the host trees only through wounds in which the heartwood is exposed. The most common point of entrance is a broken or dead limb, although in the western and southwestern United States it also frequently enters through fire scars and other basal wounds.

In Arkansas and eastward, where the species of oaks differ from those in the West and Southwest, the rot caused by this fungus is apparently confined chiefly to the branches and upper portion of the trunk. This may be due to the fact that often there are one or more large dead branches in the crown of the tree, while there are very few on the lower part of the trunk. The fungus has therefore little or no opportunity to enter the bole of the tree below the crown.

When the fungus enters the stub of a broken limb, it grows downward through heartwood of the stub till it enters the trunk, when it spreads

both upward and downward through the heart of the tree. When it enters near the base of the tree, it sometimes spreads upward throughout the heart of the entire trunk. This occasionally was noted in the white oak in Arkansas, and such trees were worthless for lumber.

In Oklahoma and to the west oaks frequently have large dead branches at any point on the trunk of the tree. Through these the fungus may enter. The rot therefore is not confined as closely to the upper half of the trees as it is in the oaks of Arkansas and to the east. Probably 50 per cent of the western oaks attacked by this fungus have the rot throughout the entire trunk.

The sporophores of *Polyporus dryophilus* when growing on oak are usually found only on living trees; however, specimens have been collected growing on the boles and large branches of trees which had been cut for at least three years, and in one instance a sporophore was found growing directly on the top of an old oak stump. The fungus apparently continues to grow slowly in the infected trees after they have been cut, but rarely fruits under such conditions. There is no evidence at hand concerning the possibility of infection by *P. dryophilus* after the death of the tree.

In no instance in Arkansas has the junior writer found this fungus entering a tree through fire scars or other wounds on the butt of oaks, even where fire scars were common. The rot always originated at some point above the base of the tree, and if a tree was found in which the rot had reached the collar of the tree it came from above and not from below. All of the sporophores of this fungus found on specimens of Populus were growing on dead or dying trees. In this case the fungus is able to fruit abundantly on both living and dead trees.

This fungus on Populus seems to be truly parasitic, to some extent at least. It attacks the trunks of the trees chiefly, entering the heartwood through dead limbs after they are broken off. The trees die by either breaking off or in some cases apparently from the direct effect of the fungus, which attacks the sapwood when the disease becomes far advanced.

Several instances were found in oak where the fungus had apparently penetrated and killed small areas of the sapwood and formed its sporophores at these points.

No positive evidence was found indicative of the age of the fungus in either oaks or poplars or of its rate of growth in the infected tree. Apparently trees of all ages are susceptible to this rot, provided the branches are old enough to have formed heartwood.

SPOROPHORE OF POLYPORUS DRYOPHILUS

Polyporus dryophilus has a hard, granular, sandstone-like core, a character that is unique and not possessed by any other polypore known to the writers. The sporophore of this plant, represented by numerous specimens collected by the writers in various portions of the United

States, in every instance shows this hard granular core (Pl. IX, figs. 2 and 4) exactly as figured and described by Hartig (1878) in case of his *P. dryadeus*. This core extends back some distance into the tree in oaks; it is usually irregularly cylindrical while in the tree, but on its emergence from the tree it swells into a tuberous or spheroid mass and finally occupies the central and rear part of the sporophore (Pls. IX, fig. 2, and X, fig. 6). If the sporophore is formed from a large branch hole, it is usually of the applanate type, with a small core, but when the sporophore forms directly on the body of the tree, as it usually does, the shape is tuberous, unguliform, or even subglobular (Pl. IX, figs. 2 and 4), with the bulk of the sporophore composed of hard, granular core. This core usually has white mycelial strands (Pl. IX, fig. 4). The sporophore of *P. dryophilus*, therefore, has normally three distinct kinds of structures (Pl. X, fig. 4): (1) The hard, granular core; (2) the fibrous layer which surrounds this core except at the rear; (3) the layer of tubes on the lower surface. Specimens are often found, however, especially from the western part of the United States, in which this fibrous layer may be entirely absent between the tubes and the granular core (Pl. IX, fig. 4).

Polyporus dryophilus is known in Europe under at least five different names: *Polyporus fulvus* Fries, *P. friesii* Bresadola, and *P. corruscans* Fries for the form on oak, and *P. vulpinus* Fries and *P. rheades* Persoon for the form on poplar. The identity of *P. dryophilus* with the *P. corruscans* Fries (Pl. X, fig. 4) and with *P. rheades* Persoon is based on the specimens of these plants found in the Lloyd Herbarium at Cincinnati, Ohio. If these specimens are correctly determined, then the American plant is identical with the European plants named above. Authentic specimens of the form of *P. dryophilus* found on species of Populus were seen by the junior writer at the New York Botanical Gardens in collections from Finland and Sweden and also from Maine. In the Lloyd Herbarium at Cincinnati, Ohio, are collections under the name of *P. rheades* on *Populus tremula* from Sweden (Pl. X, fig. 3) and Denmark, and a collection from Austria on *Quercus ilex*. In the Cryptogamic Herbarium of Harvard University there is a collection on *Populus grandidentata* Michx. from New Hampshire, while in the Laboratory of Forest Pathology there is a fine collection on *Populus tremuloides* Michx. (Pl. X, figs. 1, 2, and 5) from near Steamboat Springs, Colo.

This fungus on Populus agrees in all essential characters with the form of *Polyporus dryophilus* found on oak. The sporophores are, however, somewhat smaller than those usually found on oak and approach the applanate type (Pl. X, figs. 1 and 2). The hard granular core is always present, but is formed between the sapwood and bark (Pl. X, fig. 4), as the fungus is able to rot the sapwood, as well as the heart of this host. It therefore does not have to depend on branch holes or other openings through the sapwood in order to form its sporophores as it does in the oak.

DESCRIPTION OF THE SPOROPHORE OF POLYPORUS DRYOPHILUS

Pileus thick, unequal, smooth to irregular nodulose, often convex below, unguliform (Pl. IX, fig. 5), subglobose (Pl. IX, fig. 1) or even applanate (Pl. X, fig. 1), simple or rarely subimbricate (Pl. X, figs. 2 and 5), rigid, 4 to 22 cm. broad by 3 to 13 cm. wide (measured from front to rear of sporophore) by 2.5 to 21 cm. thick (measured from pore surface to top of sporophore); surface at first densely tomentose, becoming scabrous to smooth with age; tomentum rather stiff, deciduous, short, maize yellow to ferruginous; surface of weathered sporophores after the tomentum has partially disappeared, zonate, zones several, narrow, extending entirely around the pileus near its margin (Pl. IX, fig. 3); margin in immature specimens thick, usually obtuse (Pls. IX, figs. 1 and 5, and X, figs. 1 and 2), concolorous or slightly pallid, entire or undulate; context dual, consisting of a hard granular core, surrounded except in the rear by a thin fibrous layer; core subglobose to pulvinate, 3 to 10 cm. thick, ferruginous to cinnamon brown, granular, often with white mycelial strands ramifying through it (Pl. IX, fig. 2); fibrous layer on upper surface of core a mere pellicle about 0.5 mm. thick, expanding in mature specimens into a border (Pl. IX, fig. 4) 1 to 3 cm. wide and 5 to 15 mm. thick; fibrous layer between tubes and core thin, 1 to 15 mm., usually not over 6 to 8 mm., fibrous layer zonate, concolorous; tubes slender, concolorous or slightly paler than core in some specimens, rather fragile in age, 5 mm. to 3.5 cm. long, shorter near margin of sporophore, usually about 1 cm. long; mouths regular when young, but becoming somewhat irregular and angular at maturity (Pls. IX, fig. 6, and X, fig. 8), two or three to a mm., glistening, grayish when young, becoming hazel to russet with age, edges thin; spores broadly oval, smooth, ferruginous, 4.8 to 8 by 3.4 to 6.4μ, average size 6.54 by 4.85μ when on oak (Pl. IX, fig. 6), 4.8 to 6.4 by 3.4 to 5.6μ, average size 5.82 by 4.05μ when on poplar (Pl. X, fig. 8); cystidia none; hyphæ ferruginous, 4 to 6μ. The sporophores found on oak in Arkansas and in the eastern portion of the United States often have shorter tubes (Pl. IX, fig. 4), slightly smaller spores, and a more applanate pileus than those found in the Western States (Pl. IX, fig. 2).

DISTRIBUTION OF POLYPORUS DRYOPHILUS

The rot caused by *Polyporus dryophilus* is very widely distributed in the United States, having been found in 23 States: Arizona, Arkansas, California, Colorado, Illinois, Kansas, Louisiana, Maine, Maryland, Mississippi, Missouri, Nebraska, New Hampshire, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Texas, and Wisconsin. Authentic specimens of the fungus have also been examined from the following foreign countries: Austria, Denmark, Finland, France, Germany, and Sweden. The sporophores of the fungus are frequent and the rot caused by the fungus is exceedingly common in New Mexico, Arizona, and California.

DISTRIBUTION IN EUROPE

Polyporus dryophilus is known to occur in Europe as follows, the junior writer having examined authentic specimens:

GERMANY (?):

On *Quercus* sp. (F. P. 12404)[1].

[1] "F. P." = Forest-Pathology Investigations number.

GERMANY:

On *Quercus* sp.—ROBERT HARTIG (from Herb. Von Tubeuf); PFEIFFER (Herb. N. Y. Bot. Gard.), part of the type specimen for *Polyporus friesii;* **Berlin,** LLOYD (Herb. Lloyd).

AUSTRIA:

On *Quercus ilex.*—Travnik, REV. E. BRANDIS (No. 08864, Herb. Lloyd).

DENMARK:

On *Populus* (?) sp.—J. LIND (No. 06339, Herb. Lloyd).

FINLAND:

On *Populus* sp.—**Murtiala,** Sept., 1882 (No. 5724, Herb. N. Y. Bot. Gard.).

SWEDEN:

On *Quercus robur.*—**Stockholm,** ROMELL, Oct., 1903 (Herb. N. Y. Bot. Gard.), and a second specimen, collector unknown (Herb. N. Y. Bot. Gard.).

On *Quercus* sp.—**Upsala,** LLOYD (No. 08936, Herb. Lloyd); **Stockholm,** ROMELL (No. 08936, Herb. Lloyd).

On *Populus tremula.*—**Stockholm,** ROMELL, June 25, 1905 (Herb. N. Y. Bot. Gard.), and a second specimen, MURRILL (Herb. N. Y. Bot. Gard.); **Stockholm,** HAGELUND (No. 08985, Herb. Lloyd).

On *Populus* sp.—HAGELUND (No. 09375, Herb. Lloyd); **Stockholm,** ROMELL (No. 08414, Herb. Lloyd).

FRANCE:

On *Pinus* (?) sp.—**Fontainebleau,** P. HARIOT (No. 08880, Herb. Lloyd); this specimen from France was reported as on pine, and has spores similar in size and shape to those growing on species of Populus and a sporophore much like those found on species of Quercus.

DISTRIBUTION IN UNITED STATES

Polyporus dryophilus has been reported from and collected in the various States of this country as follows:

MAINE:

On *Populus tremuloides.*—**Piscataquis Co.,** MURRILL, in 1905 (Herb. No. 1901, N. Y. Bot. Gard.).

On *Betula* (?) sp.—Near **Moosehead Lake,** VON SCHRENK, in 1899 (Herb. N. Y. Bot. Gard.).

NEW HAMPSHIRE:

On *Populus grandidentata.*—**Chocorua,** FARLOW (?), in 1904 (Herb. W. G. Farlow).

NEW YORK:

On *Quercus alba.*—**Bronx Park,** MURRILL, in 1908 (F. P. 1416).

PENNSYLVANIA:

On *Quercus* (?) sp.—**Kittanning,** SUMSTINE 32 (Herb. N. Y. Bot. Gard.).

MARYLAND:

On *Quercus alba, Q. coccinea,* and *Q. minor.*—**Takoma Park,** HEDGCOCK, in 1910.

OHIO:

On *Quercus* (?) sp.—M. A. CURTIS, "Ex. Berkeley" (Herb. W. G. Farlow); **Preston** (?), A. P. MORGAN, in 1887 (Herb. N. Y. Bot. Gard.); **Preston, A. P.** MORGAN (0598); and **Akron,** C. D. SMITH (07556, Herb. Lloyd).

VIRGINIA:

On *Quercus prinus.*—**Elkins,** LONG, in 1913 (F. P. 12418).

On *Quercus* (?) sp.—**Falls Church,** LUTTRELL, in 1902 (Herb. N. Y. Bot. Gard.).

NORTH CAROLINA:

On *Quercus prinus.*—**Brim,** LONG.

On *Quercus velutina.*—**Jonesboro,** P. L. BUTTRICK, in 1913 (F. P. 15045).

TENNESSEE:

On *Quercus alba* and *Q. velutina*.—**Roan Mountain,** HEDGCOCK, in 1913.

MISSISSIPPI:

On *Quercus lyrata*.—**Sand Point,** HEDGCOCK, in 1908.

LOUISIANA:

On *Quercus lyrata*, *Q. marilandica*, *Q. michauxii*, and *Q. phellos*.—Near **Bogalusa,** HEDGCOCK, in 1908.

MISSOURI:

On *Quercus alba*.—**Mountain Grove,** HEDGCOCK.

On *Quercus imbricaria*.—Near **St. Louis,** J. N. GLADFELTER (No. 1214, Herb. Mo. Bot. Gard.).

On *Quercus marilandica*.—**Steelville,** SPAULDING; **Mountain Grove,** HEDGCOCK.

On *Quercus minor*.—**Webster Groves,** A. H. GRAVES, in 1909 (F. P. 1617).

On *Quercus palustris*.—**Mountain Grove,** HEDGCOCK.

ILLINOIS:

On *Quercus alba*.—Near **Plymouth,** HEDGCOCK, October, 1909.

WISCONSIN:

On *Populus* sp.—**Oakfield,** in 1903 (Herb. Univ. Wisc.).

On *Quercus macrocarpa*.—**Rockton,** L. H. PAMMEL, in 1886 (Herb. N. Y. Bot. Gard.).

NEBRASKA:

On *Quercus macrocarpa*.—Near **Nelson,** HEDGCOCK, in 1911.

OKLAHOMA:

On *Quercus alba*.—**Cache,** LONG, in 1912 (F. P. 12407).

On *Quercus marilandica*.—**Cache,** LONG, in 1912 (F. P. 12420).

On *Quercus minor*.—**Cache,** LONG, in 1912 (F. P. 12408, 12416, 12419, 12421).

On *Quercus prinoides*.—**Cache,** LONG, in 1912 (F. P. 12414).

ARKANSAS:

On *Quercus alba*.—TREAT (F. P. 12102), **Casteel** (Ozark National Forest; F. P. 12137, 12140, 12142, 12154, 12219, 12243, 12263, 12268, 12296, 12402, 12403, 12405, 12406, 12409, 12413, 12425); **Bigflat** (F. P. 12158, 12156, 12160), LONG, in 1912: **Womble** (F. P. 12413), **Cedar Glades** (F. P. 12422), LONG, in 1913; **Fayetteville** and **Farmington,** HEDGCOCK, in 1906.

On *Quercus digitata*.—**Casteel,** LONG, in 1912 (F. P. 12272).

On *Quercus minor*.—**Whiterock,** LONG, in 1912 (F. P. 12240).

On *Quercus texana*.—**Mountain View,** LONG, in 1912 (F. P. 12415).

On *Quercus velutina*.—**Casteel,** LONG, in 1912 (F. P. 12410).

TEXAS:

On *Quercus marilandica*.—Near **Boerne,** HEDGCOCK, in 1909 (F. P. 760).

On *Quercus minor*.—**Austin** (F. P. 12424) and **Denton** (F. P. 12423), LONG in 1912.

On *Quercus nigra*.—Near **Houston,** HEDGCOCK, in 1909.

On *Quercus phellos*.—Near **Houston** and near **Boerne,** HEDGCOCK, in 1909.

On *Quercus texana*.—Near **Houston** and near **Boerne,** HEDGCOCK, in 1909 (F. P. 762).

On *Quercus velutina*.—Near **Boerne,** HEDGCOCK, in 1909.

On *Quercus virginiana*.—Near **Houston** and near **Boerne,** HEDGCOCK, in 1909 (F. P. 320).

COLORADO:

On *Populus tremuloides*.—**Steamboat Springs,** HEDGCOCK, in 1912 (F. P. 3894).

On *Quercus gambelii*.—**Square Top Mountain** (San Juan National Forest; F. P. 9229); near **Mancos** (Montezuma National Forest); southeast of **Delta** (Uncompahgre National Forest); HEDGCOCK, in 1912.

NEW MEXICO:

On *Quercus arizonica*.—**Pecos,** LONG, in 1913 (F. P. 12412).

On *Quercus emoryii*.—**Mogollon Mountains** HEDGCOCK, in 1911.

On *Quercus gambelii*.—**Sandia Mountains** (Manzano National Forest), HEDGCOCK, in 1906 (F. P. 126, 230); in 1908 (F. P. 270, 551–553, 558); near **Pinos Altos** (Gila National Forest), HEDGCOCK, in 1909 (F. P. 811, 812); in **Alamo National Forest**, L. L. JANES, 1909 (F. P. 1142); **Mogollon Mountains, Bear Creek Canyon,** and **Trout Creek** (Gila National Forest), HEDGCOCK and LONG, in 1911 (F. P. 9837); **Cloudcroft,** LONG, in 1911 (F. P. 12015); **Pecos,** LONG, in 1912 (F. P. 12426).

On *Quercus oblongifolia*.—Near **Mogollon,** HEDGCOCK, in 1911.

ARIZONA:

On *Quercus arizonica*.—**ChiricahuaMountains,** H. D. BURRALL, in 1908; near **Sedona** (Coconino National Forest), HEDGCOCK, in 1910; **Santa Catalina Mountains,** HEDGCOCK, in 1911.

On *Quercus chrysolepis*.—**Sedona,** HEDGCOCK, in 1910.

On *Quercus emoryii*.—**Chiricahua Mountains,** BURRALL, in 1908; **Groom Creek** and **Crown King** (Prescott National Forest), HEDGCOCK, in 1910; **Santa Catalina Mountains,** HEDGCOCK, in 1911.

On *Quercus gambelii*.—**Groom Creek** (F. P. 4557), **Crown King** (F. P. 4877), **Sedona** (F. P. 4941), and near **Flagstaff,** HEDGCOCK, in 1910; **Santa Catalina Mountains,** HEDGCOCK and LONG, in 1911 (F. P. 9801).

On *Quercus hypoleuca*.—Near **Pinos Altos,** HEDGCOCK, in 1909.

On *Quercus oblongifolia*.—**Groom Creek** and **Crown King** (F. P. 4876) and near **Sedona,** HEDGCOCK, in 1911; **Santa Catalina Mountains,** HEDGCOCK, in 1911.

On *Quercus toumeyi*.—**Santa Catalina Mountains,** HEDGCOCK, in 1911.

CALIFORNIA:

On *Quercus californica*.—**Scott River Valley** (Klamath National Forest), HEDGCOCK, in 1909 (F. P. 1886); near **Mirror Lake** (Yosemite Park), **Clarks** (Plumas National Forest), **North Fork,** and **O'Neals** (Sierra National Forest), MEINECKE, in 1910; near **El Portal** and **Yosemite** (Yosemite Park), HEDGCOCK and MEINECKE, in 1910 (F. P. 4794); near **Kennett,** HEDGCOCK and MEINECKE, in 1911 (F. P. 9649).

On *Quercus chrysolepis*.—**El Portal** and **Yosemite,** HEDGCOCK and MEINECKE, in 1910; **North Fork** (Sierra National Forest), MEINECKE, in 1910.

On *Quercus garryana*.—**Scotts River** and **Mount Marble** (Klamath National Forest), HEDGCOCK, in 1910 (F. P. 1847).

On *Quercus lobata*.—**Stanford University,** C. F. BAKER, in 1902 (Herb. Univ. of Wisconsin); near **Chico,** HEDGCOCK, in 1909; **Dobe** and **Italian Bar** (Sierra National Forest), MEINECKE, in 1910.

On *Quercus wislizeni*.—**El Portal, Yosemite,** and near **Raymond,** HEDGCOCK, in 1910; near **Kennett,** HEDGCOCK, in 1911.

On *Quercus* sp.—**Crane Valley** (Sierra National Forest), and **El Portal,** MEINECKE, in 1910.

OREGON:

On *Quercus garryana*.—Near **Mount Hood** (Oregon National Forest) and **Rogue River Valley,** Siskyou National Forest), HEDGCOCK, in 1909 (F. P. 1717); near **Medford,** HEDGCOCK, in 1911 (F. P. 9611).

On *Quercus californica*.—**Rogue River Valley,** HEDGCOCK, in 1909.

From the foregoing data the following trees are attacked by the disease caused by *Polyporus dryophilus: Quercus alba, Q. arizonica, Q. californica, Q. chrysolepis, Q. coccinea, Q. digitata, Q. emoryii, Q. gambelii, Q. garryana, Q. hypoleuca, Q. imbricaria, Q. ilex, Q. lobata, Q. lyrata, Q. macrocarpa, Q. marilandica, Q. michauxii, Q. minor, Q. nigra, Q. oblongifolia, Q. palustris, Q. phellos, Q. prinoides, Q. prinus, Q. robur, Q. texana, Q. velutina, Q. virginiana,* and *Q. wislizeni; Populus grandidentata, P. tremula,* and *P. tremuloides; Betula* (?) sp., and *Pinus* (?) sp.

CONTROL OF THE PIPED ROT OF POLYPORUS DRYOPHILUS

The piped rot caused by *Polyporus dryophilus* is one of several important heart-rots of oaks in the United States. Suggestions made for its control will apply more or less to all of these. So long as oak trees are allowed to stand long past maturity in our wood lots and forests, heart-rots will continue to be common. The practice of leaving uncut in a lumbered area all the badly diseased trees, especially those with heart-rot, is radically wrong from the standpoint of proper forest sanitation, for this practice enables heart-rotting fungi to maintain themselves in the forest while the new generation of trees slowly develops and attains the age at which they form heartwood and thus become susceptible to the attacks of heart-rotting fungi. Trees diseased with heart-rot ought not to be left for seed trees wherever it is possible to leave healthy ones for this purpose. In hardwood forests it is often not necessary to leave seed trees, owing to the abundant sprout production, and the presence of young trees intermingled among the more mature ones.

Trees in the wood lot should be inspected annually, and all trees evidently rotted at the heart should be removed. If the trunk of a tree diseased with heart-rot is struck with an axe, it does not ring with a clear sound. The presence of the fruiting body of *Polyporus dryophilus* on a tree also is evidence of the presence of the piped rot and of the necessity of removing the tree. Sporophores on trees should be removed whenever found.

In large forested areas it is not possible to personally inspect the trees every year nor to search the forests annually for sporophores, although the present prices of good white-oak lumber nearly justify the expense necessary in a system of careful forest sanitation. It will certainly pay in lumbering tracts of oak and other valuable hardwoods to cut out all unsound or diseased trees, remove the parts that can be used, and burn the remainder. Many trees under the present methods of lumbering are left standing because they are decayed in the trunk near the butt. If cut down, these trees would be found to contain enough lumber to pay for the cost of operation. Such a procedure will lead to a better and closer utilization of our gradually decreasing supply of hardwood lumber, especially of white oak.

The destruction of all trees that are rotted in the heart in timber sales will be a step far in the direction of control for these diseases of timber. A new forest grown on areas lumbered with due regard to sanitation will be certain to be nearly free from heart-rot.

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PLATE VIII

Fig. 1.—*Quercus alba:* Crescent-shaped "soak," the initial stage of the piped rot produced by *Polyporus dryophilus;* from Arkansas.

Fig. 2.—*Quercus alba:* A radial view of the rot in a limb, showing delignification; from Arkansas.

Fig. 3.—*Quercus oblongifolia:* A radial view of rot, showing delignification; from Arizona.

Fig. 4.—*Quercus alba:* A final stage of the rot, radial view, with more complete delignification; from Arkansas.

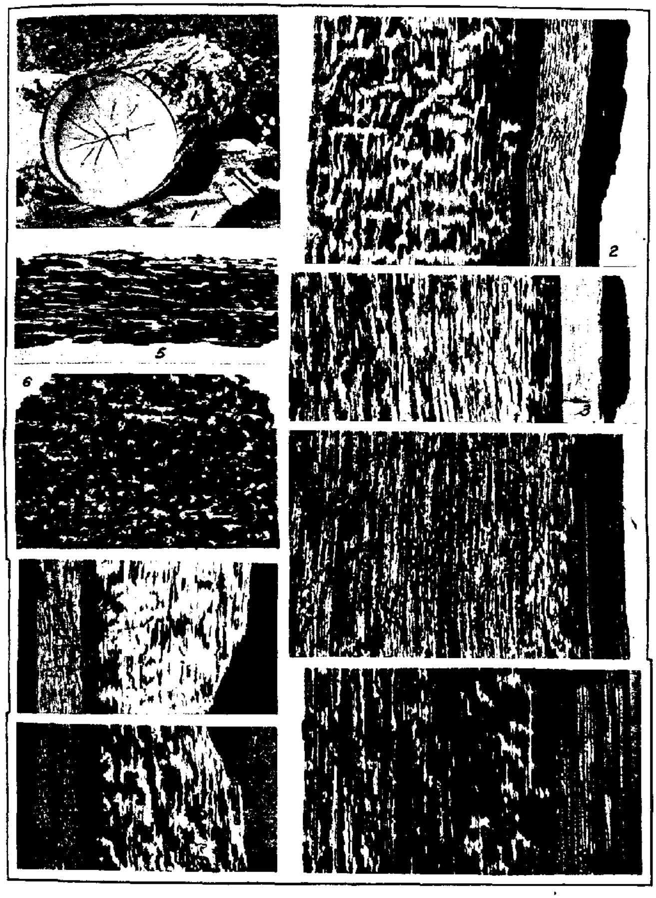
Fig. 5.—*Quercus alba:* A tangential view of the rot, showing delignification in pockets; from Arkansas.

Fig. 6.—*Quercus alba:* An end view showing a cross section from the same tree as the preceding; from Arkansas.

Fig. 7.—*Quercus* sp.: A section of oak from Von Tubeuf, sent to the junior writer as a specimen of the rot caused by *Polyporus dryadeus* in Europe.

Fig. 8.—*Quercus* sp.: The reverse side of the specimen shown in the preceding.

Fig. 9.—*Quercus* sp.: A section of oak from Europe, obtained by Von Schrenk, with a piped rot similar to that of *Polyporus dryophilus.*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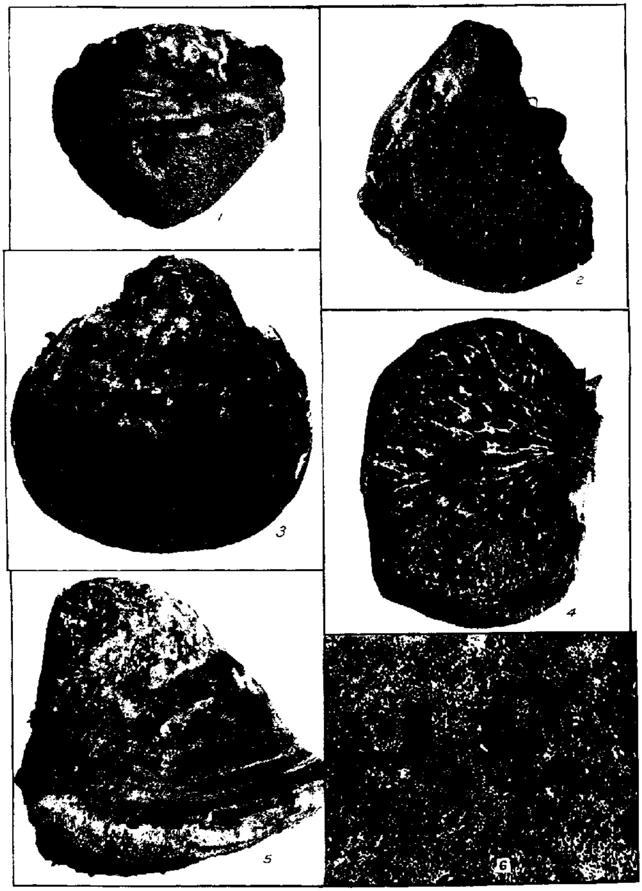


PLATE IX

Fig. 1.—A sporophore of *Polyporus dryophilus*, tuberous form on *Quercus gambelii*; from Arizona.

Fig. 2.—Sectional view of a sporophore of *Polyporus dryophilus* on *Quercus gambelii*, showing the hard granular core with whitish mycelial strands; also the pore layer; from New Mexico.

Fig. 3.—A sporophore of *Polyporus dryophilus* on *Quercus californica*, showing the upper surface with a faint zonation; from California.

Fig. 4.—A section through a sporophore of *Polyporus dryophilus* on *Quercus garryana*, showing the structure of the hard granular core; from California.

Fig. 5.—A front view, showing the margin of the same sporophore as in figure 3, representing the ungulate form.

Fig. 6.—A view of the pore surface of an applanate sporophore of *Polyporus dryophilus* on *Quercus alba*; from Arkansas.

PLATE X

Fig. 1.—A sporophore of *Polyporus dryophilus*, front view showing the margin, on *Populus tremuloides;* from Colorado.

Fig. 2.—A second sporophore from the same tree as figure 1, showing an imbricated form.

Fig. 3.—A view of the upper surface of a sporophore of *Polyporus rheades* on *Populus tremula;* from Stockholm, Sweden.

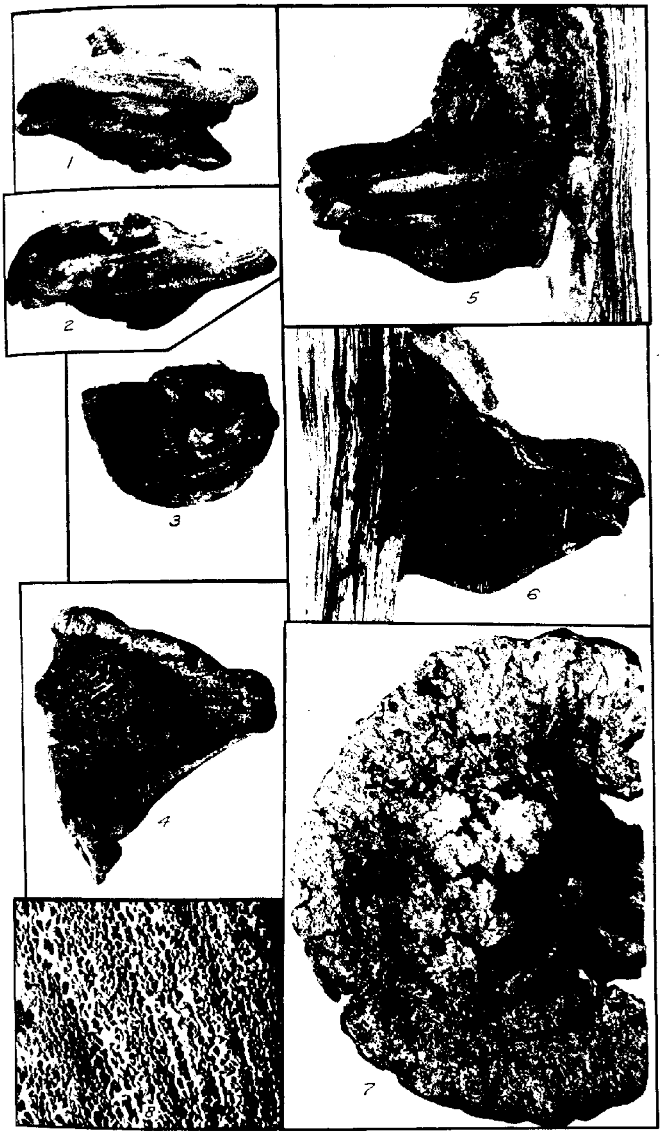
Fig. 4.—A sectional view of a sporophore of *Polyporus corruscans* on Quercus; from Upsala, Sweden.

Fig. 5.—A side view of an imbricate sporophore of *Polyporus dryophilus*, applanate form on *Populus tremuloides;* from Colorado.

Fig. 6.—A sectional view of the same sporophore as in the preceding figure, showing the hard granular core and whitish mycelial strands.

Fig. 7.—A view of the upper surface of an applanate sporophore of *Polyporus dryophilus* on *Quercus alba;* from Arkansas.

Fig. 8.—The pore surface of a sporophore of *Polyporus dryophilus* on *Populus tremuloides;* from Colorado.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PRELIMINARY AND MINOR PAPERS

DECOMPOSITION OF SOIL CARBONATES

By W. H. MacIntire,
Soil Chemist, Tennessee Agricultural Experiment Station

Investigations recently conducted at the University of Tennessee Agricultural Experiment Station have led to the discovery that the composition of soils is such as to make inhibitory any long-continued occurrence therein of magnesium carbonate, and the conclusion has been drawn that magnesium carbonate does not exist as a solid mineral in our humid soils.

The research has demonstrated that the affinity of magnesia for silica s such that soils long since alkaline from excessive treatments of calcium carbonate are able to dissipate the CO_2 of magnesium carbonate under sterile, moist conditions. It has been further demonstrated that the affinity of magnesia for silica is so great that precipitated magnesium carbonate is extensively decomposed by pure SiO_2 and also by the closely allied compound titanium oxid, which occurs almost universally to an appreciable extent in soils.

Analyses to determine residual carbonates at the end of one year established the fact that precipitated magnesium carbonate in amounts chemically equivalent to 16,070 pounds of $CaCO_3$ per acre in excess of the quantity indicated by the Veitch method as necessary to correct acidity had been entirely decomposed by each of three distinct types of unleached soil. A loam, a sandy loam, and a silty loam were used in the study. In substantiating the work the loam soil was subjected to eight check treatments in field rim experiments. In each of these eight instances precipitated $MgCO_3$ equivalent to over 15 tons of a good grade of limestone per 2,000,000 pounds of soil had entirely disappeared at the end of eight weeks, when the first analyses were made for residual carbonates. No drainage took place during this 8-week interval.

Comparisons between residual carbonates from limestone and dolomite treatments showed at the end of 9 months' exposure to weather 22,000 pounds of $CaCO_3$ per 2,000,000 pounds of soil for the limestone treatment as compared to 11,000 pounds of $CaCO_3$ as a residue from the dolomite.

The investigations have also determined that the absence of carbonates subsequent to applications of magnesium oxid has been erroneously attributed to persistent causticity of the magnesia, which is shown to be very readily converted to the carbonate, while this in turn is decomposed by siliceous substances.

The use of $CaCO_3$ as a check has shown that the affinity of lime for silica is far greater than has been supposed, and the work has demonstrated that the lime-silica reaction in soils is an important factor in the conservation of lime applied in practice. While the lime-silica reaction

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does not approach the magnesia-silica reaction in rapidity, it is shown by field data that the lime-silica reaction continues long after the attaining of alkalinity and that the reaction is extensive.

Toxicity due to excessive treatments of magnesium carbonate after its conversion to silicates was demonstrated by plant growth.

The progress of the work of the writer and associates is reported in detail in Tennessee Experiment Station Bulletin 107.

A FUNGOUS DISEASE OF HEMP

By VERA K. CHARLES, *Assistant Mycologist*, and ANNA E. JENKINS, *Scientific Assistant*, *Office of Pathological Collections and Inspection Work, Bureau of Plant Industry*

In September, 1913, the attention of the Office of Pathological Collections and Inspection Work was called to a fungous disease which had attacked a variety of hemp (*Cannabis sativa*) grown for experimental purposes by Mr. L. H. Dewey, Botanist in Charge of Fiber-Plant Investigations. Although the disease did not make its appearance until the plants were almost full grown, it was very rapid in its action, only about two weeks having elapsed between the time that the disease was first noted and the death of many of the plants. One of the early symptoms of the disease was the wilting and drooping of the leaves. The foliage turned brown and finally died, but remained attached to the plant longer than in the normal condition. In nearly all instances the fungus first attacked the outer ends of some of the upper, though rarely the highest, branches of the plant. In some cases the branches above and below the diseased area remained uninjured for some time. It was observed that the disease spread more above than below, but that the affection of the plant became general in about two weeks. Although the disease appeared to attack the outer ends of the branches first, the main stem below the base of the diseased branch became bleached and afterwards darkened by the formation of the perithecia of the fungus (Pl. XI).[1]

The hemp was grown from seed originally introduced from China, having been grown for experimental purposes during a period of 10 years. Its cultivation had been generally successful, and until the season of 1913 no difficulty had been experienced from fungus attack.

All of the plants in the plots in which the disease was most serious were from the seed of one single selected plant, the third best of the crop of 1912. This plant showed no evidence of disease and was remarkable for its purple-colored foliage. Selections had been continuous for 10 generations without any admixture of other strains. Three or four plants of this plot which were especially precocious were marked as soon as it was observed that they were pistillate, and each one of these plants was attacked by the disease. So general was the attack that among the 135 pistillate plants of this plot 128 were destroyed by the fungus, representing a loss of about 95 per cent of this plot. Later the disease appeared in a larger plot of 320 and in less than four weeks 66⅔ per cent of the plants had been attacked.

A microscopic examination of the first diseased material collected on September 12, 1913, revealed the presence of small, black pycnidia, containing minute, hyaline spores on branched conidiophores. These characters, together with the absence of stroma, placed the fungus in the genus Dendrophoma. (Fig. 1, *E* and *F*.) This appears to be the first occurrence of the fungus in America. A second examination of the diseased hemp about three weeks later showed pycnidia containing spores

[1] Most of the field observations were made by Mr. L. H. Dewey, who mentions the occurrence of this disease in an article entitled "Hemp" in the Yearbook, U. S. Dept. of Agriculture, for 1913, p. 283–346, fig. 17–21, pl. 40–46. 1914.

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characteristic of the genus Macrophoma (fig. 1, *D*). At the same date an immature ascomycete was observed on material which had been allowed to remain on the ground. The final collection on November 3 showed an ascomycetous fungus present in large amounts on the hemp which had been spread for dewretting, while the two other spore forms were absent, or present only in negligible amounts, having matured before the development of the ascospores. The asci were borne in perithecia similar in appearance to the pycnidia of the two other forms (fig. 1, *B*).

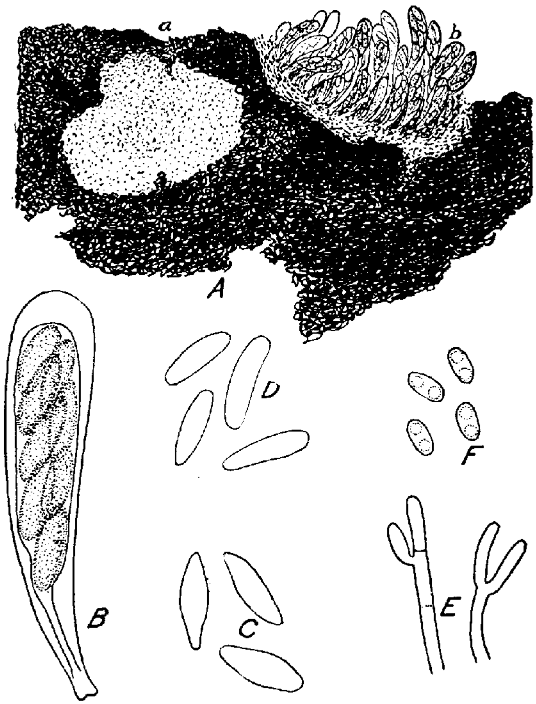

FIG. 1.—Microscopic characters of the hemp fungus *Botryosphaeria marconii*. *A*, Sketch of a section of stroma from culture, showing develooing perithecia: *a*, microconidial stage, *b*, ascosporic stage, × 840. B, An ascus with ascospores, × 840. *C*, Ascospores, × 840. *D*, Macroconidia, × 840. *E*, Conidiophores of the Dendrophoma stage, × 1920. *F*, Microconidia, × 1920. (Drawing by J. Marion Shull.)

The spores were hyaline to slightly colored, nonseptate, and fusoid (fig. 1, *C*). A probable connection between these three forms suggested itself to the authors, and cultures were started to prove, if possible, that these stages are different phases in the life history of one fungus. The spores of the Dendrophoma form are designated as microconidia and those of the Macrophoma stage as macroconidia.

Cultures were made on various media, but as the fungus developed luxuriantly and rapidly upon corn meal, that medium was adopted for

the cultural work. The fungus developed in the same sequence as in nature, the Dendrophoma stage appearing first, regardless as to whether the cultures were made from microconidia, macroconidia, or ascospores. Sections of the pycnidia made at a later date demonstrated that the development of the macroconidia followed the microconidia in the same pycnidium. In sections made at a still later date asci were found developing in the same locule with the mature macroconidia. The three spore forms of the fungus as developed in culture agreed perfectly in character with those found in nature. The variations observed in size and shape of macroconidia and shape of the asci were also exhibited by the fungus in nature. The one notable difference, however, was in the stronger development of stroma in the cultures. Since the Dendrophoma spores and the Macrophoma spores developed in the same pycnidia, the macroconidia and ascospores in the same perithecia, and all three forms in the same stroma, it is definitely proved that these three forms represent the different stages in the life history of one fungus (fig. 1, *A*).

From the critical microscopical study of the Dendrophoma stage of this fungus in nature and in culture it is shown to be morphologically identical with a specimen of *Dendrophoma marconii* described by Cavara in Italy in 1887.[1] No stroma is produced as the fungus occurs on the host, although a well-developed stroma is produced in culture. This stromatic development is suggestive of the genus Dothiorella, but it is not a constant character, and as the fungus agrees so closely with Cavara's description of Dendrophoma on hemp,[2] the authors consider these two forms to be identical.

During the course of the microscopic study of Dr. Cavara's material a second type of spore was found which corresponded exactly with the macrospores discussed in this paper. No mention of these was made in Dr. Cavara's paper, however, and the writers were unable to determine whether or not they had been observed by him.

Among the few fungi described on hemp and related genera no species were found possessing the characters of the perfect stage of the fungus here discussed. In 1831 a fungus was observed by Schweinitz on hemp, and was called by him *Sphaeria cannabis* Schw.[3] This species is of historical interest only, for the description is too meager to be of any taxonomic value. The characters of the ascosporic stage place the fungus in the genus *Botryosphaeria* as defined by Saccardo.[4] As the imperfect stage of this fungus is considered identical with the first described form, *Dendrophoma marconii* Cav., the specific name is retained and the fungus is designated *Botryosphaeria marconii* (Cav.) Charles and Jenkins.

Botryosphaeria marconii (Cav.) Charles and Jenkins.

Perithecia globose, perforate, diseased area pale olive buff to gray, 140 to 160 μ in diameter; basidia bearing microconidia mostly dichotomously branched, septate, hyaline; microconidia polymorphic, ovate, elliptical, or terete, continuous, hyaline, 4 to 5½ by 1½ to 2 μ; macroconidia fusiform or ellipsoid, continuous, hyaline to glaucous, 16 to 18 by 5 to 6 μ: basidia of macroconidia slender, generally 12 to 15 μ in length; asci clavate, 8-spored, 80 to 90 by 13 to 15 μ; paraphyses filiform; spores fusoid, hyaline to pale light grape green, 16 to 18 by 7 to 8 μ. Microconidia, macroconidia, and asci produced in the same perithecium. On *Cannabis sativa*.

[1] Briosi, Giovanni, and Cavara, Fridiano. I Funghi Parassiti delle Piante Coltivate od Utili. no 20. Pavia, 1887. *Exsiccatæ.*

[2] Cavara, Fridiano. Appunti di patologia vegetale (alcuni funghi parassiti di piante coltivate.) *In* Atti Ist. Bot. Univ. Pavia, [s. 2], v. 1, p. 426. 1888.

[3] Schweinitz, L. D. von. Synopsis fungorum in America boreali media degentium secundum observationes. *In* Trans. Amer. Phil. Soc., n. s., v. 4, p. 222, no. 1741. 1834.
Saccardo, P. A. Sylloge Fungorum . . . v. 2, p. 432. Patavii, 1883.

[4] Saccardo, P. A. Sylloge Fungorum . . . v. 1, p. 456. Patavii, 1882.

In view of the serious nature of the disease and its sudden appearance in America it has seemed best to present this preliminary paper. The true parasitic nature of the fungus was evident from its effect on the growing plants, but its parasitism was further demonstrated by the successful isolation of the fungus from the interior tissue of thoroughly disinfected stems. Owing to limited time and opportunity for extensive field observations, many questions relating to the pathological phase of the subject remain unsolved. Problems pertaining to the method of infection by the fungus, its manner of dissemination, and control measures for the disease are still subjects of investigation by the Office of Pathological Collections and Inspection Work.

PLATE XI

A hemp plant, showing upper branches attacked by the fungus *Botryosphaeria marconii*.

A MORE ACCURATE METHOD OF COMPARING FIRST-GENERATION MAIZE HYBRIDS WITH THEIR PARENTS

By G. N. Collins,

Botanist, Office of Acclimatization and Adaptation of Crop Plants, Bureau of Plant Industry

INTRODUCTION

That the crossing of two distinct varieties of maize usually results in an increase of vigor and larger yields in the first, or F_1, generation has come to be generally recognized. The amount of the increase, however, varies greatly in different hybrids, and in many cases the increase is not large enough to be determined by ordinary experimental methods, if it exists at all.

So far as known, no case has been reported where a decrease below the mean yield of the parents has been adequately demonstrated. It is highly desirable to know the conditions under which significant increases occur, but thus far little light has been thrown on this important point. If really incompatible varieties exist, a study of their behavior in hybrid combinations should afford a favorable opportunity to learn something regarding the conditions necessary for large increases. One serious obstacle to learning the factors involved in the increased yields of first-generation hybrids is the difficulty of accurately comparing the vigor and yield of a hybrid with that of the parent varieties.

Hybrids in maize are made either by hand pollination between individual plants or by planting in alternate rows the varieties to be hybridized and removing the tassels from all the plants of one of the varieties.

The customary method of comparing the behavior of a hybrid with its parents is to plant the hybrid seed in rows or blocks alternating with similar areas planted with the seed of the parents. If the series is repeated a sufficient number of times, reliable averages may be obtained, but in actual practice the number of repetitions is usually limited by lack of seed or space.[1]

In making a comparison between a hybrid and its parents where the hybrid is made by planting the varieties in alternate rows, the question arises as to what seed will best represent the parents. If the original seed of the parent varieties is used, it will be one year older than the hybrid seed, and the uncertain element of deterioration with age is introduced.[2] By saving the seed from the plants used as a source of pollen in making the hybrid, fresh seed of the male parent can be secured, but if fresh seed of the female parent is obtained, it must be grown at some distance from the place where the hybrid is made. To use seed grown under different conditions introduces an element of uncertainty that

[1] In experiments with maize extending over a number of years in many different localities, we have found that with rows 100 feet long and the series repeated 10 times, it has seldom been possible to detect with assurance differences in yield of less than 10 per cent.

[2] For a discussion of this point, see Hartley, C. P., Brown, E. B., Kyle, C. H., and Zook, L. L. Cross-breeding corn, U. S. Dept. Agr., Bur. Plant Indus. Bul. 218, p. 13-16, 1912. One and two-year-old seed of selection No. 119a, the variety used as male parent in the Maryland experiments, occurred side by side 42 times. The average superiority of the new seed was 7 ± 1.3 per cent.

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may be as serious as that incurred by the use of old seed. If the conditions of growth where the pure seed is produced are more favorable than those under which the hybrid seed is produced, natural selection will be less rigorous. There is also the possibility of direct effect of environment on the yielding power of the seed and the possibility of new-place effect.

A further disturbing factor lies in the differences between the individual plants that produce the hybrid seed and those producing the pure seed which is to represent the parental varieties. When seed from a large number of plants is used, these differences tend to counterbalance each other and give an average of value for practical purposes, but information which might extend our knowledge regarding the nature and causes of the increase may be completely obscured by this method of averaging.

Some of these difficulties can be avoided if the hybrid seed is obtained by hand pollination. By this means seed of both parent varieties of the same age as the hybrid seed and grown under similar conditions can be secured. Inaccuracies due to diversity among individual plants will, however, be increased, since the number of plants involved will necessarily be smaller, and, as before, differences in the behavior of individual crosses which might throw light on the nature of the increases will be masked if conclusions are based upon averages. To avoid this last difficulty, the individual hybrid ears may be kept separate and an ear-to-row method of making comparisons with the parents may be applied.

Differences in the breeding value of individuals are now appreciated in the breeding of pure strains and have led to the adoption of the method of separating the offspring of individuals into progeny rows. The results here reported show a diversity among the hybrid ears that result from crossing different plants of the same parent varieties that is even greater than that usually found between pure seed ears of a single variety, and the evidence indicates that individual diversity in hybrids will be found as important as in pure varieties.

In comparing an individual maize hybrid with its parents account must be taken of the fact that to behave normally maize must be cross-pollinated, and to secure cross-pollinated seed of the parent varieties two plants of each variety must be used, but only one plant of each variety can be represented in an individual hybrid ear. To avoid in some measure these sources of inaccuracy the method followed in the experiments here described is suggested.

DESCRIPTION OF METHOD

To compare the behavior of two varieties, which may be called A and B, with that of a hybrid between them, two plants were selected in each variety, A1 and A2 in the one variety and B1 and B2 in the other variety. The following hand pollinations were made: A1 × A2, A2 × B1, B1 × B2, and B2 × A1. The result is two hybrid ears and one cross-pollinated ear of each variety. It is believed that the mean yield produced by seed from the two hybrid ears compared with the mean yield produced by seed from the two pure seed ears gives a fair measure of the effects of hybridization. By making two hybrids involving all the plants used in producing the pure seed ears individual differences that affect the yielding power of the pure seed ears are similarly represented in the hybrids. Thus, in both the

parents and the hybrids the average yield represents the mean yielding power of the four parent plants, the only difference being the way in which the individuals are combined.

To secure the most accurate comparison of the yield of the four ears, one seed from each of the ears was planted in each hill. The different kinds were identified by their relative position in the hill. To place the seeds accurately, a board 4 inches square was provided with a small, pointed peg 2 inches long at each corner. These pegs were forced into the soil at each hill, making four holes, one for each of the four kinds, only one seed being planted in a hole. The board was always placed with two sides of the board parallel to the row. It was necessary to exercise extreme care in dropping the seeds to avoid changing the position of the kinds. The best way to obviate mistakes of this kind is to make all the holes of a row in advance and to go down the row with one kind of seed at a time.

At harvest time the seed produced by each plant was weighed and recorded separately. All hills that lacked one or more plants were excluded and the comparison confined to hills in which all four kinds were represented. The method of handling the yields was to determine the mean yield of the four kinds in each hill and to state the yield of each of the four plants as a percentage of the mean of the hill in which it grew. The percentage standing of each kind in all the hills was then averaged to secure the final expression of the relative behavior of the four kinds.

This method of comparison is similar to the ingenious plan originated by C. H. Kyle,[1] for use in ear-to-row breeding. Kyle's method is to plant each of the ears to be tested in a separate row and in each hill to plant one seed of a standard, or check, ear with which all ears are compared. Since comparative and not absolute yields are desired in the study of hybrids and with only four kinds to compare, the introduction of a check in the present experiment would have increased the space occupied by the experiment without lessening the experimental error.

APPLICATIONS OF METHOD

The hybrid tested by this method was a cross between the Egyptian, a white sweet corn, and the Voorhees Red, a related sweet variety with red aleurone.[2] The two hybrids secured in accordance with the foregoing method were designated Ph96 and Ph97. The use of the Voorhees Red variety as one of the parents made the comparison unusually difficult. This variety produces a considerable percentage of albino seedlings, and since no albino seedlings reach maturity, the result was a large number of hills with less than the full complement of plants. Eighty-four hills were planted, but only fifty-eight matured plants of all four kinds.

The comparative yield of the four kinds is given in Table I. To illustrate the meaning of these determinations, let us take the yield of the Egyptian variety. The number 112.8 indicates that the yield of 58 Egyptian plants averaged 112.8 per cent of the mean yield per plant of all four kinds—that is, 12.8 per cent above the mean.

[1] Kyle, C. H. Directions to cooperative corn breeders. U. S. Dept. Agr., Bur. Plant Indus., B. P. I.—564, 10 p., 1910.

[2] The strain of Egyptian corn used in this experiment was from commercial seed secured from J. M. Thorburn & Co. in 1911. The original source of the Voorhees Red was an ear kindly supplied by Prof. Byron D. Halsted, of the New Jersey State Agricultural Experiment Station, in 1907.

The mean of the two parents is 84.2 ± 3.0 per cent of the general yield. The mean of the two hybrids is 115.9 ± 3.3 per cent. The mean yield of the hybrids is thus 31.7 ± 4.5 per cent higher than the mean of the parents, and this increase is ascribed to the effects of crossing.

TABLE I.—*Yield and height of the Egyptian and Voorhees Red varieties of sweet corn and two hybrids between them*

[Determinations expressed as average percentages of the mean of the four kinds.]

Variety of corn.	Yield.	Height.
	Per cent.	*Per cent.*
Egyptian	112.8 ± 4.6	111.3 ± 1.0
Voorhees Red	55.6 ± 4.0	84.0 ± .9
Hybrid Ph96	89.0 ± 5.1	100.0 ± 1.2
Hybrid Ph97	142.8 ± 4.3	103.6 ± 1.1

A striking feature of the results obtained is the difference between the yield of the two hybrid ears, which amounts to 53.8 ± 6.7 per cent. Had the ear Ph96 alone been taken as representing a hybrid between these varieties, the hybrid would have exceeded the average of the parents by only 4.8 per cent, a difference upon which no reliance could be placed. If, on the other hand, the ear Ph97 had been taken, the difference in favor of the hybrid would have appeared as 58.6 per cent.

The relative height of the four kinds was determined in the same manner as the yield—that is, the height of each plant was compared with the mean height of all the plants of the hill in which it grew, the latter being taken as 100. The average heights expressed in this way are given in column 2, Table I.

The average height of the parents is 97.6 ± 0.7 per cent of the general mean. That of the hybrids is 101.8 ± 0.8 per cent. The difference is 4.2 ± 1.1 per cent. There is, then, a distinct increase in the height of plants as a result of crossing, but the increase is much less than the increase in yield, and the difference between the two hybrids is much less than was the case with the yield.

It has usually been found that the increase that follows crossing affects the vegetative characters even more than the reproductive. If height be taken as an index of vegetative vigor, the reverse would seem to be true in the present cross.

Increased vegetative vigor may have resulted in an increase of the branches rather than of the main stalk. To definitely settle this point, it would have been necessary to weigh or measure all of the suckers. This was not done, but the number of suckers was recorded for each of the kinds, and the difference, though small, indicates that a part of the increased vegetative vigor of the hybrids was expressed in the production of suckers. A total of 18 suckers was produced in the two pure-seed rows, while 35 were produced in the two hybrid rows. The association between vegetative vigor and yield is further shown by the fact that the hybrid Ph97 exceeded the hybrid Ph96 both in yield and in the production of suckers. It should be borne in mind, however, that an increased yield and an increased production of branches may not always be thus associated. It is to be expected that under some conditions excessive

branching may result in a decreased yield. Hence, if some hybrids show reduced yields, this fact alone should not be taken as proving an exception to the general rule that the first generation of a hybrid shows increased vigor.

The method of comparison here used brings the plants into close competition, and it may be urged that the differences between the kinds are as a result unduly accentuated. With a view to detecting a possible effect of competition, the yield of the plants in hills with four plants was compared with plants of the same varieties in hills with less than four plants.

In P9, P19, and Ph97 the yield per plant was slightly higher in the 4-plant hills than in the 3-plant hills. The differences were, however, insignificant. In Ph96 the yield of the plants from the 3-plant hills exceeded that from the 4-plant hills by 67 grams per plant. The number of 3-plant hills was so small, however, that little confidence should be placed in the difference, which was but three times the probable error.

An attempt was made to secure a more accurate comparison by correcting for the differences in the yield of the different kinds, thus making it possible to compare the yield per plant of all the 4-plant hills with that of all the 3-plant hills. The average yield per plant in the 4-plant hills was 211 ± 7 grams. The average yield of the 3-plant hills was 227 ± 10. The difference of 16 ± 12 grams is therefore not significant.

With such a large experimental error it is of course not impossible that the crowding of the plants has a tendency to reduce the yield, but if so the difference is too small to be measured by the means employed, If crowding operated to accentuate differences, it might also be expected to retard the date of flowering. The average number of days to flowering was, however, the same in the 4-plant hills and in the hills with less than four plants, being 72.4 days in both. Thus there is no evidence that the growing of the four kinds close together affects the relative yield of the kinds, and when ample space is provided between the hills, viz, 4 by 5 feet, as in this experiment, it is believed that this source of inaccuracy is insignificant.

The conditions of the experiment here reported constitute a severe test of the method of comparison by individual hills. The kinds tested were very dissimilar, while the soil of the experiment was unusually uniform. The gain in accuracy secured by using the hill as the unit of comparison, instead of averaging the yield of all the plants of a kind, may be measured by a comparison of the standard deviations or the coefficient of variability observed when the yields are compared by the two methods.

When the yield of each plant was compared with the average of all the plants of the same kind, the coefficient of variability was 5.42 ± 0.17. When the yield of each plant was compared with mean yield of the hill in which it grew the coefficient of variability was 5.05 ± 0.13. There is, thus, a slight gain in accuracy, notwithstanding the exceptional uniformity of the soil where the experiment was tried. With less uniform soil conditions the advantages secured by making the comparison on the basis of individual hills would increase.

The dates when the first staminate flowers opened and when the first silks appeared were recorded for all the plants. The average number of days from planting to flowering is shown in Table II.

TABLE II.—*Average time from planting to flowering of varieties of maize*

Variety.	Number of days to first pollen.	Number of days to first silks.
Egyptian	73.0±0.1	73.9±0.3
Voorhees Red	72.1± .2	77.1± .3
Hybrid Ph96	72.0± .2	73.5± .4
Hybrid Ph97	72.5± .2	73.6± .4

With respect to the appearance of the staminate flowers the only significant difference is the slightly later flowering of the Egyptian variety. With respect to the appearance of silks, the Voorhees Red, the low-yielding variety, was distinctly later. The average time between the opening of staminate flowers and the appearance of silks was less than one day in the Egyptian and five days in the Voorhees Red variety. Both hybrids were intermediate, with 1.5 and 1.1 days, respectively, between the average time of the appearance of pollen and silks.

A further comparison of the hybrids with their parents with respect to minor characters brings to light a number of striking differences. A comparison of the characters measured is made in Table III.

TABLE III.—*Comparison of minor characters of maize hybrids with their parents*

Character.	Egyptian maize.	Voorhees Red maize.	Hybrid Ph96.	Hybrid Ph97.	Average of parents.	Average of hybrids.
Height ... cm.	206 ±1.6	157 ±2.6	185 ±3.4	193 ±2.9	182 ±1.5	189 ±2.2
Number of suckers	.21± .04	.11± .02	.14± .03	.48± .08	.160± .022	.312± .041
Total number of leaves	17.4 ± .13	15.8 ± .12	16.4 ± .13	10.8 ± .14	16.6 ± .08	16.6 ±1.0
Exsertion of tassel [a] ... cm.	4.3 ± .3	4.9 ± .3	5.2 ± .2	3.5 ± .3	4.6 ± .20	4.4 ± .17
Length of axis of tassel [b] ... cm.	12.7 ± .3	16.6 ± .3	16.4 ± .3	14.1 ± .3	14.1 ± .19	15.2 ± .20
Length of central spike [c] ... cm.	28.1 ± .8	23.2 ± .8	24.5 ±1	29.7 ±1.1	25.6 ± .58	27.1 ± .74
Number of primary branches in tassel	14.4 ± .25	19.5 ± .32	20.1 ± .35	15.4 ± .17	16.9 ± .21	17.7 ± .22
Number of secondary branches in tassel	5 ± .1	6.2 ± .2	7.2 ± .3	4.7 ± .2	5.6 ± .25	5.9 ± .18
Length of longest leaf	59.3 ± .5	84 ± .8	89.6 ±1	92.9 ± .7	86.6 ± .47	91.2 ± .62
Number of nodes above longest leaf	5.6 ±1.0	4.5 ±1	4.9 +1.2	5.1 ±1.0	5.1 ± .7	5 ± .78
Number of nodes above ear	5.3 ± .8	4.9 ± .4	4.7 ± .6	4.9 ± .6	5.1 ± .36	4.8 ± .41

[a] Measured from the top of the uppermost leaf sheath to the lowest tassel branch.
[b] Measured along the axis from the insertion of the first to the insertion of the last primary tassel branch.
[c] Measured from insertion of last tassel branch to tip of tassel.

In all of the characters measured, with the exception of "Number of nodes above the longest leaf" and "Number of nodes above the ear," there was a measurable difference between the two parents. In the "Number of suckers" and in the four tassel measurements there was also a significant difference between the two hybrids. The mean of the hybrids shows a close approximation to the mean of the parents in the total number of leaves, exsertion of tassel, length of the central spike, number of secondary branches, and number of nodes above the ear and the longest leaf. The characters in which the hybrid exceeds the

parents are for the most part those more closely associated with vigor—viz, height, number of suckers, and length of leaf. The differences between the two hybrids are such that without exception Ph96 stands closer to the Voorhees Red variety and Ph97 closer to the Egyptian variety. It is probably a coincidence that in both hybrids the resemblance is to the female parent.

CONCLUSIONS

So large a proportion of first-generation maize hybrids have been found to give increased yields and the increase is frequently of such magnitude that the utilization of this factor of productiveness becomes a practical question. It is therefore highly desirable to understand the reasons why some crosses give favorable results and others give little or no increase over the yield of the parents. A necessary step in this direction is to develop a reliable method of measuring the effect of crossing, apart from other factors that influence yield.

The development of satisfactory methods of comparing the yield of first-generation hybrids with that of their parents has been retarded by (1) a failure to fully appreciate the importance of individual diversity in hybrids, (2) the abnormal behavior of self-pollinated maize plants, and (3) the difficulty of securing for comparison hybrids and parents with identical ancestry. It is believed that the method here described avoids these difficulties and affords more accurate means of comparing first-generation maize hybrids with their parents.

The method is illustrated by an experiment in crossing two varieties of sweet corn in which it was found that the progeny from one hybrid ear yielded nearly double that of the other hybrid ear involved in the experiment. To have taken either ear alone would have led to entirely erroneous conclusions regarding the increase secured as a result of crossing. The increase in yield due to crossing as measured by the method here proposed was 31 per cent.

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